SUBCOURSE EN5453

EDITION 7

SOILS ENGINEERING

AIPD

READINESS/ PROFESSIONALISM THRU GROWTH

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM

US ARMY ENGINEER OFFICER

SOILS ENGINEERING
SUBCOURSE EN5453

Ten Credit Hours

GENERAL

The Soils Engineering Subcourse is designed to teach you how to determine soil strength of swelling, non-swelling, and free-draining soils using CBR; determine after soil emplacement, field density and moisture content; use test data to determine stabilizing agents, the quantities required, and the construction sequence for given soils; and, direct a deliberate soil survey. This subcourse is presented in five lessons, each lesson corresponding to a terminal learning objective as indicated below.

Lesson 1: BASIC SOIL PROPERTIES

TASK: Identify the steps used to evaluate Basic Soil Properties.

CONDITIONS: Given this subcourse, a No. 2 pencil, paper and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly answering 75% of the examination questions.

Lesson 2: SOIL CLASSIFICATION AND FIELD IDENTIFICATION PROCEDURES

TASK: Classify Soils Using Unified Soil Classification System Field Identification Procedures.

CONDITIONS: Given this subcourse, a No. 2 pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly answering 75% of the examination questions.

Lesson 3: SOIL SURVEYS

TASK: Describe the Procedures Used to Direct a Deliberate Soil Survey for a Proposed Military Construction Project.

CONDITIONS: Given this subcourse, a No. 2 pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly answering 75% of the examination questions.

Lesson 4: FIELD CONTROL PROCEDURES

TASK: Determine Field Density and Moisture Content after Soil Emplacement and Direct Corrective Actions.

CONDITIONS: Given this subcourse, a No. 2 pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly answering 75% of the examination questions.

Lesson 5: CALIFORNIA BEARING RATIO

TASK: Determine Soil Strength of Non-swelling, Swelling, and Free-draining Soils Using CBR.

CONDITIONS: Given this subcourse, a No. 2 pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly answering 75% of the examination questions.

***** IMPORTANT NOTICE *****

THE PASSING SCORE FOR ALL ACCP MATERIAL IS NOW 70%.

PLEASE DISREGARD ALL REFERENCES TO THE 75% REQUIREMENT.

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INTRODUCTION

The key to our modern Army is MOBILITY. The Army must be able to move anywhere at any time.

It is your responsibility as a military engineer to provide this mobility. To do this, you must build roads, airfields, storage areas, maintenance facilities, waterways, and shore facilities. All these construction projects have one thing in common: soil. Soil is either a construction material or a foundation material in each of the projects noted. Consequently, if you are going to carry out your responsibilities as a military engineer, you must have a basic understanding of soils engineering. This knowledge of soils will enable you to best provide more economical construction.

NOTE: Soils stabilization and compaction are also important in construction projects. If you would like more information on these two characteristics, study EN5458, Flexible Pavements.

Lesson 1
BASIC SOIL PROPERTIES

TASK: Identify the steps used to evaluate basic soil properties.

CONDITIONS: Given this subcourse, a No. 2 pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by responding correctly to 75% of the examination questions.

CREDIT HOURS: 2

REFERENCE: FM 5-530

INTRODUCTION

Knowledge of the physical properties of soil is essential in solving many problems associated with the design and construction of military roads, airfields, and foundations. Unfortunately, the usual urgency of construction in the Theater of Operations frequently does not permit the development of complete subsurface investigations. Therefore, the engineer locating complete soil information must rely upon his own ability to identify soils and to judge their engineering characteristics. The engineer must make a prompt decision as to the best possible location, the minimum amount of material needed to complete the project on schedule, and the best means for controlling and improving the load bearing capabilities of the soil.

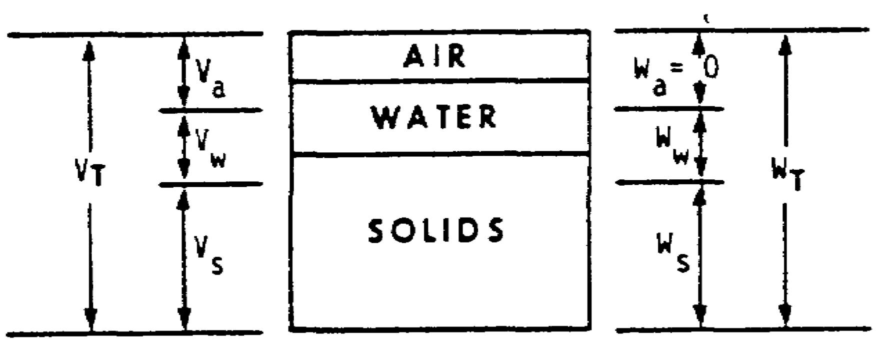
Learning Event 1
EVALUATE RELATIVE STRENGTH OF SOILS BASED ON PHYSICAL PROPERTIES

Soil is a heterogeneous (non-uniform) accumulation of non-adhesive grains that are separated by voids of varying sizes. These voids may contain air, water, or organic matter. Different soil types contain different mixes of these components.

THE MAJOR COMPONENTS

A unit volume of soil is made up of three major components: air, water, and solids produced by disintegrated and decomposed rocks. Separating a mass of soil into its components sexes as the basis for weight-volume relationships (Figure 1) which you will use in later lessons.

FIGURE 1. MAJOR SOIL COMPONENTS



V_T = Total Volume
V_v = Volume of Voids
V_s = Volume of Solids
V_a = Volume of Air
V_w = Volume of Water

W_T = Total Weight
W_a = Weight of Air = 0
W_w = Weight of Water
W_s = Weight of Solids

Of the three components, the solids will contribute most to the strength of the soil. Therefore, the more solids per unit volume, the higher the density of the material will be. <u>The higher the density, the greater the strength</u>.

PARTICLE GRAIN SIZE

Soils are divided into groups based on the size of the particle grains. The standard size groups employed in the Unified Soil Classification System are shown in Table 1.

TABLE 1. STANDARD SIZE GROUPS

Size Groups	Sieve Size	
	Passing	Retained on
Cobbles	No maximum size*	3-inch
Gravels	3-inch	No. 4
Sands	No. 4	No. 200
Fines	No. 200	No minimum size

* In military engineering, maximum size of cobbles is accepted as 40 inches, based upon maximum jaw opening of the crushing unit.

Particles passing the #200 sieve but larger than 0.002mm to 0.005mm are called silt.

Common practice distinguishes the sizes through the use of sieves. A sieve is a screen attached across the end of a shallow cylindrical frame. The screen permits particles smaller than the openings to fall through and retains the larger particles. All standard sieves fall into two categories:

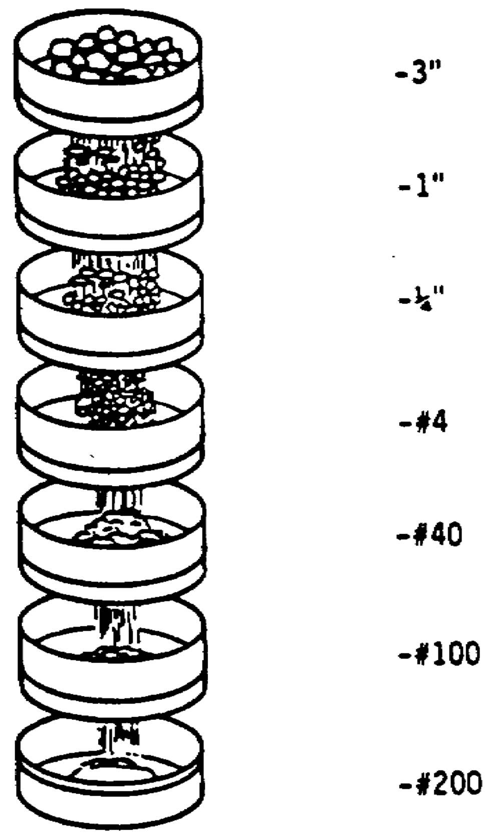
- The larger sized sieves, 3 inches to 1/4 inch, are designated by the size of the actual opening in the wire mesh.
- The smaller sized sieves, #4 to #200, are designated by the number of openings per linear inch.

Sieves used by the military engineer have square openings and are designated as 2-, 1 1/2-, 1-, 3/4-, and 1/4 inch sieves and US Standard #4, 10, 20, 40, 60 and 200 sieves. A #4 sieve has four openings per linear inch or 16 openings per square inch, and so on.

SIEVE ANALYSIS

To perform a sieve analysis of the distribution of grain sizes in a given soil sample, use a nest of sieves like the one shown in Figure 2. Then measure the amount remaining on each sieve and describe each amount as a percentage by weight of the entire sample.

FIGURE 2. A NEST OF SIEVES-COMMON SIEVE SIZES



Weigh the total oven-dry soil sample and then shake the dry, loose material through the nest of sieves. The sieve analysis may be performed directly upon soils which contain little or no fines, such as a clean sand, or soils in which the fines may be readily separated from the coarse particles. Soils which have little dry strength and can be crushed easily in the fingers would generally fall into the latter category. If the character of the fines is such that the fine material adheres to the coarse particles and is not removed by dry sieving action, the sample is soaked in water and washed over the #200 sieve. The soil retained on the #200 sieve is then oven-dried, the washing loss (fines) determined, and the analysis conducted as before.

Documenting the Results on a Grain Size Distribution Graph

The results of a sieve analysis are recorded either tabularly on a Sieve Analysis Data Form (DD Form 1206), Figure 3, or graphically on a Grain Size Distribution Graph (DD Form 1207), Figure 4. The tabular form is best used when comparing results to 9 sets of specifications. The graph form permits the plotting of a grain size distribution curve. This curve illustrates the distribution and range of particle sizes, and is particularly helpful in determining the soil classification and engineering characteristics.

FIGURE 3. SIEVE ANALYSIS DATA FORM

SIEVE ANALYSIS DATA		DATE: 11 JULY 1986
PROJECT: FRAUNCE THEATER	EXCAVATION NUMBER: 2	SAMPLE NUMBER: FT-P1-1
DESCRIPTION OF SAMPLE: 25 lb bag sample		PREWASHED: ☐ YES ☒ NO
WEIGHT ORIGINAL SAMPLE (gm.): 359.1	WEIGHT AFTER PREWASHING[1] (gm.):	WASHING LOSS[1] (gm.):

SIEVE OR SCREEN a	WEIGHT RETAINED ON SIEVE (gm.) b	PASSING SIEVE WEIGHT (gm.) c	PASSING SIEVE PERCENT d	
*	0		100	
1 1/2	0	359.1	100.0	Gravel
3/4	0	359.1	100.0	Gravel
No. 4	51.0	308.1	85.8	Sand
10	40.9	267.2	74.4	Sand
20	83.3	183.9	51.2	Sand
40	75.4	108.5	30.2	Sand
100	49.9	58.6	16.3	Sand
NUMBER 200	47.4	11.2	3.1	Fines

A. WEIGHT SIEVED THROUGH NO. 200 (gm.): 11.2	ERROR (Original weight - total weight of fractions)(gm.): 359.1-359.1=0.0
B. WASHING LOSS[1] (gm.): —	
TOTAL PASSING NO. 200 (gm.) (A + B): 11.2	PERCENT ERROR (Error (gm.) / Original weight (gm.) x 100). 0 %
TOTAL WEIGHT OF FRACTIONS (Total of all entries in Col. b) (gm.): 359.1	

REMARKS

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)
Paul Massin	Paul Massin	John Steck

[1]For prewashed samples only. *Maximum particle size.

DD FORM 1 AUG 57 1206

FOR INSTRUCTIONAL PURPOSES ONLY

FIGURE 4. GRAIN SIZE DISTRIBUTION GRAPH

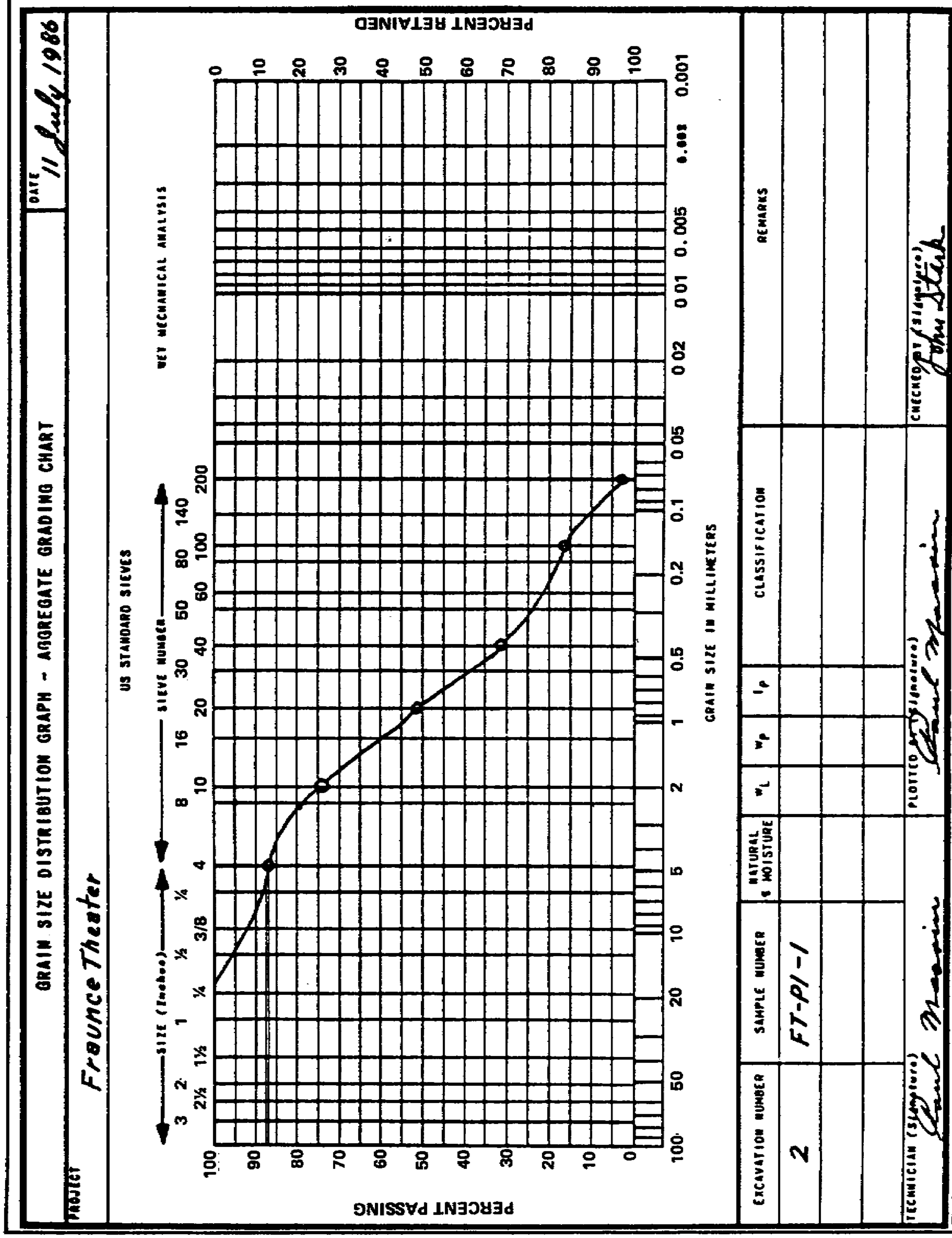
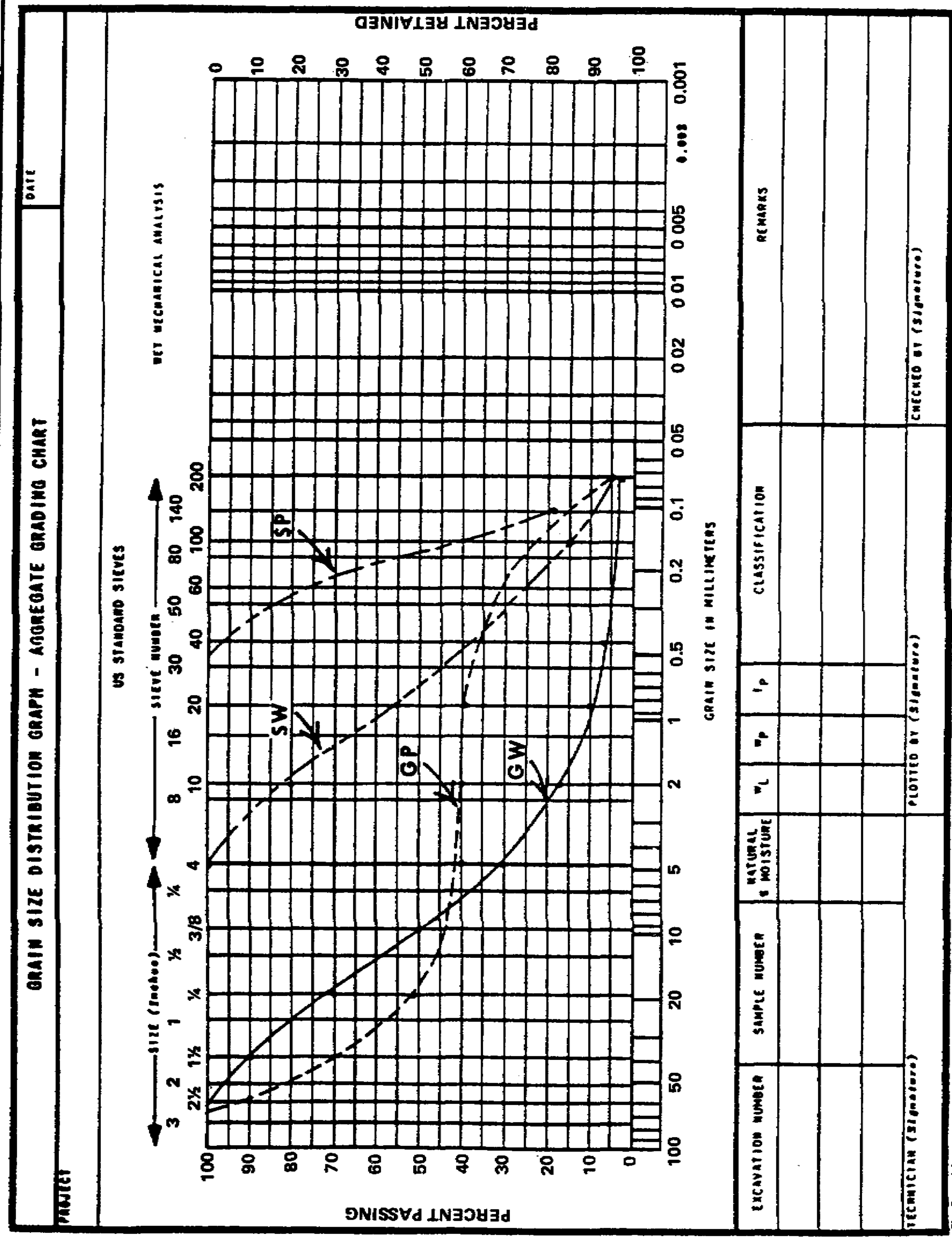


FIGURE 5. VARIOUS WELL-GRADED AND POORLY-GRADED SOILS



Compare Figures 3 and 4. Using the Sieve Analysis Data Form it is easy to calculate the percentages of the major soil materials: gravels, sand, and fines. Cobbles are not included in the analysis. Figure 4 shows the particle distribution curve of a predominantly sandy soil. Figure 5 shows distribution curves for two well-graded and two poorly-graded soil types. “G” stands for gravel, “S” stands for sand. Therefore, a GW is a soil which is well-graded and predominantly gravel.

Well-graded soils (GW and SW) are separated by a long curve spanning a large size range with a constant or gently varying slope. Uniformly graded soils (SP curve) would be represented by a steeply doping curve spanning a narrow size range, and the curve for a gap-graded soil (GP curve) will flatten out in the area of the grain size deficiency.

You may also calculate the percentage of each grain type using the Grain Size Distribution Graph. Note that the abscissa (the horizontal coordinate of a point) of the graph is divided into percent by weight. To calculate the percent of a given grain type (for example, sand) begin by tracing a line straight down from the sieve size that retains gravel, #4. Where that line intersects the distribution curve, trace a line horizontally to the left and note the percent value where that line intersects the abscissa. Next trace a line directly down from the #200 sieve size at the top. Where that line intersects the curve, make a line horizontally to the left again. Subtract the second percent value from the first. The difference equals the percentage of sand in the soil sample.

The rule stated earlier, the higher the density the stronger the soil, applies to grain size. Generally, coarse grain soils can be compacted to a greater density than fine grained soils. Frequently, the largest practical size for use in a construction project is one-half the compacted thickness. (Refer to Table 1.)

Note that fines can be <u>silts</u>, <u>clays</u>, or a <u>combination of both</u>.

Particle Size

The shape of the particles influences the strength and stability of a soil. The two basic shapes are bulky and platy.

- Bulky shapes are subdivided depending on the amount of weathering which has acted upon them. They may be angular, subangular, subrounded, or rounded (Refer to Figure 6). The angular shape shows flat surfaces, jagged projections, and sharp ridges; whereas the rounded shape has smooth curved surfaces and almost approaches a sphere. Cobbles, gravel, sand, and silt fall into the bulky shape group.

FIGURE 6. PARTICLE SHAPES

- Platy grain shapes have one dimension relatively small compared to the other two. The faces at approximately right angles to this dimension will have relatively large areas whereas the other surface will be edges and present small surfaces. Clay exhibits this shape. Coarse-grained soil particles with bulky shapes are observable by the naked eye, whereas fine grained particles with platy or bulky shapes are not.

The angular shape is preferred for construction projects. The rough sides and sharp edges interlock and provide friction for higher strength and greater resistance against penetration.

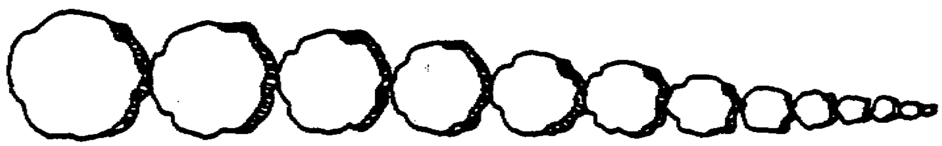
Smooth particles, even if bulky, slide over each other, providing low resistance to penetration. Platy soil is often not desirable for construction because it loses strength and cohesiveness.

Soil Gradation

Gradation is the distribution of the different size groups within a soil sample. The soil may be well-graded or poorly-graded.

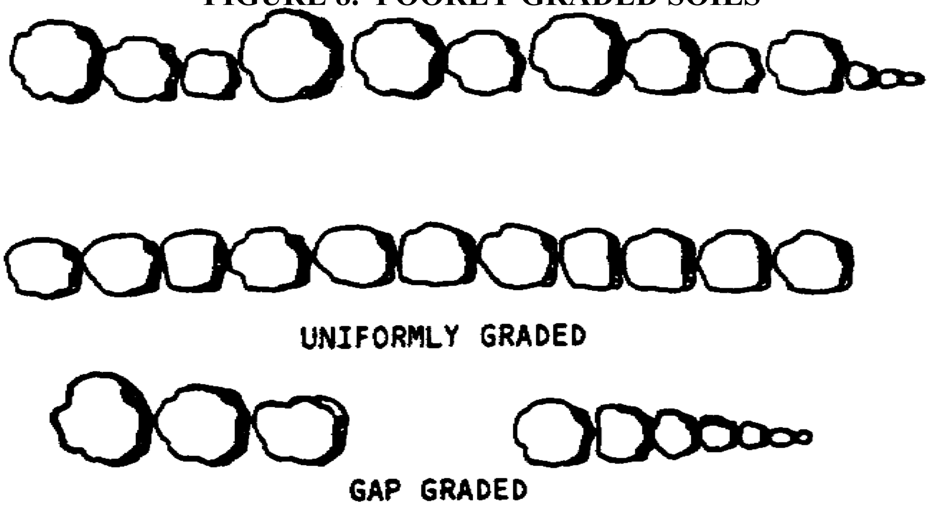
A soil, in order to be classified as well-graded, must have a good range of all representative particle sizes between the largest and the smallest. The soil in Figure 7 is well-graded.

FIGURE 7. WELL-GRADED SOILS



Poorly-graded soils are either those containing a narrow range of particle sizes or those with some intermediate sizes lacking. Soils with a limited range of particle sizes are called "uniformly graded." Soils which have some intermediate size or sizes not well represented or missing are called "gap graded," "step graded," or "skip graded." Figure 8 shows poorly graded soils.

FIGURE 8. POORLY GRADED SOILS



The well-graded soil is preferred for construction because it can be easily compacted into a dense mass with minimum voids. It has three advantages over poorly-graded soil:

- The solid mass is denser because of the interlocking of the particles which enable it to support heavier loads.
- Since the particles are fitted, it realizes the best downward load distribution.
- The tendency for displacement of individual grains by either loads or moisture is minimized because they are locked in place.

Learning Event 2
GRADATION QUALITY

To standardize the gradation criteria, two coefficients were developed based on the Grain Size Distribution Curve: the Coefficient of Uniformity (C_u) and the Coefficient of Curvature (C_c). These coefficients are defined as follows:

$$C_u = \frac{D_{60}}{D_{10}} = \frac{\text{Diameter in Millimeters of the 60\% Passing Size}}{\text{Diameter in Millimeters of the 10\% Passing Size}}$$

$$C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}} = \frac{(\text{Diameter in Millimeters of the 30\% Passing Size})^2}{(\text{Diameter in Millimeters of the 10\% Passing Size}) \times (\text{Diameter in Millimeters of the 60\% Passing Size})}$$

The grain size which corresponds to 10 percent passing on the grain size distribution curve is called Hazen's effective size; it is designated by the symbol D_{10}. The uniformity coefficient (C_u) is the ratio between the grain diameter corresponding to 60 percent passing on the curve (that is D_{60}) and the 10 percent passing (D_{10}). Hence, $C_u = D_{60}/D_{10}$.

The coefficient of curvature, designated by the symbol C_c, is written

$$C_c = (D_{30})^2/D_{60} \text{ X } (D_{10})$$

D_{10} and D_{60} have meanings previously assigned, while D_{30} is the grain diameter corresponding to 30 percent passing on the grain size distribution curve.

As we learned earlier, a soil having a good representation of all particle sizes from the largest to the smallest is defined as a well-graded soil. In the Unified Soil Classification System, well-graded gravels must have a C_u value greater than 4, and well-graded sands must have a C_u value greater than 6. Both sands and gravels must have a value for the coefficient of curvature between 1 and 3 to be well graded. Those not meeting these conditions are termed poorly-graded soils.

Therefore, in order for a soil to be considered well-graded, it must meet the following criteria:

1. Its grain size distribution must plot a smooth curve. (The curve must not have any horizontal or vertical portions and must be continuous.)

	Predominantly Gravel	Predominantly Sand
2. C_u must be	>4	>6
3. C_c must be between	1 – 3	1 – 3

To determine the Coefficients of Uniformity and Curvature using the Grain Size Distribution Graph, follow these procedures:

1. Trace a line from 60 percent on the abscissa to the right until it intersects the curve. Then drop straight down to find a value of grain size in millimeters on the ordinate. That grain size equals D_{60}.
2. Trace a line from 30 percent on the abscissa to the right until it intersects the curve. Then drop straight down to find a value of grain size in millimeters on the ordinate. That grain size equals D_{30}.
3. Repeat the same steps beginning at 10 percent to determine the value of D_{10}.

Specific Gravity of Soil. The specific gravity, designated by the ratio between the weight per unit volume of the material at a stated temperature and the weight per unit volume of water at a stated temperature, usually 20°C. The specific gravity (metric system) equals:

$$\frac{\text{Weight of Sample in Air (gms)}}{\text{Weight Sample in Air (gms) - Sample Submerged (gms)}}$$

Learning Event 3
ATTERBERG LIMITS AND CASAGRANDE PLASTICITY CHART

The specific gravity of the solid substance of most inorganic soils varies between 2.60 and 2.80. Tropical iron-rich laterite soils will generally have a specific gravity of 3.0 or more. Sand particles composed of quartz have a specific gravity around 2.65. Clays can have values as high as 3.50. Most minerals of which the solid matter of soil particles is composed will have a specific gravity greater than 2.60. Therefore, values of specific gravity smaller than 2.60 indicate the possible presence of organic matter.

SOIL MOISTURE CONTENT

The moisture content of a soil mass is often the most important factor affecting the engineering characteristics of the soil. The water may enter from the surface or it may move through the subsurface layers either by gravitational pull, capillary action, or hygroscopic action. This moisture, present in most cases, influences various soils differently, and may have the greatest implication upon the soil's behavior when subjected to loading.

To define the amount of water present in a soil sample, the term moisture content (symbol w) is used. It is the proportion of the weight of water to the weight of the solid mineral grains (weight of dry soil) expressed as a percentage or:

$$w = \frac{\text{weight of water}}{\text{weight of dry soil}} \times 100\%$$

The effects of soil moisture depend to a great extent upon grain size. Coarse-grained soils with larger voids permit easy drainage of water. They are less susceptible to capillary action. The amount of water held in these soils is less than in fine-grained soils since the surface area is smaller and excess water will tend to drain off whenever possible. The fine grains and their small voids retard the movement of water and also tend to hold the water by surface tension.

Fine-grained clay soils, called cohesive soils, exhibit plasticity within a range of moisture content. Their properties may vary from essentially liquid to almost brick-hard with different amounts of moisture. Further, clays are essentially impervious to the passage of free or capillary moisture.

A cohesive soil has considerable strength when air-dried, but has low strength when its moisture content is high. Such clays soils are composed of fine-grained particles of so-called clay minerals. Clay particles (flat, platy shapes) are capable of holding a film of absorbed water on their surfaces. Absorbed water is held by physiochemical forces and has properties substantially different from ordinary or chemically combined water. The attraction exerted by clay particles for water molecules gives these materials the property of <u>plasticity</u>.

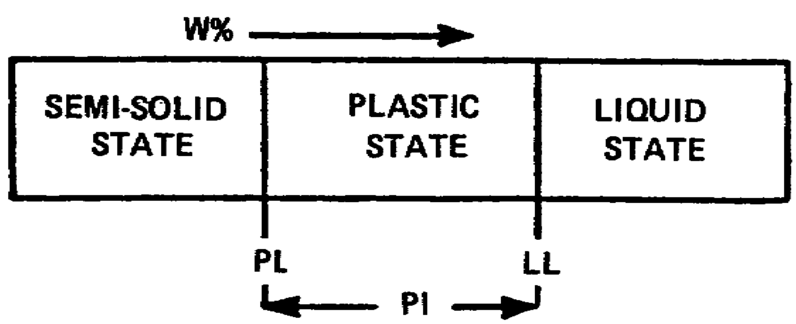
Plasticity is a property of the fine-grained portion of a soil which permits it, under certain moisture conditions, to be remolded without crumbling or rupturing. A soil or soil fraction is called plastic if, at some water content, it can be rolled out into thin threads. Plasticity could be termed a colloidal property since no mineral possesses plasticity unless it consists of particles of colloidal or clay size. Even then many minerals, such as quartz powder, do not develop plasticity regardless of how small the particles are. All clay minerals, on the other hand, are plastic. Since practically all fine-grained soils contain some clay, most of them are plastic.

The degree of plasticity a soil possesses can be used, therefore, as a general index to its clay content. Sometimes the terms "fat" and "lean" are used to describe the amount of plasticity, a "lean" clay being one that is only slightly plastic because it contains a large proportion of silt or fine sand. In engineering practice the plasticity of a soil is determined by measuring the different states a plastic soil undergoes with changing moisture conditions.

A fine-grained soil can exist in any of several different consistency states depending upon the amount of water which is present in the soil.

Simplifying this statement with the following diagram (Figure 9), let's see what we are talking about:

FIGURE 9. SOIL PLASTICITY



Semi-solid State: Material will crumble under a deforming pressure or load.

Plastic State: When a deforming pressure is applied, the material will deform and remain in that deformed state when applied pressure is released.

Liquid State: Material will be wet enough to flow under its own weight. The moisture contents at the transition zones between these states are used to classify fine-grained soils.

The boundaries between the different states in which a soil may exist are called Atterberg limits after the Swedish soil scientist who first defined them more than 40 years ago. The Atterberg limits have been defined by Dr. Arthur Casagrande, using standard laboratory procedures, as follows:

- Plastic Limit (PL): The moisture content of a soil which can be formed into a ball, then rolled to a 1/8-inch thread only once before crumbling. This is the soil moisture content at the boundary between the semi-solid and plastic states (Refer to Figure 10).

FIGURE 10. PERFORMING A PLASTIC LIMIT TEST

- Liquid Limit (LL): The soil moisture content at the boundary between the plastic and the liquid states. This boundary is defined as the water content at which two soil cakes placed in a standard cup and divided into two sections by a grooving tool, will flow together for a distance of 0.5 inch along the bottom of a groove when the cup is dropped 25 times for a distance of 1 cm at the rate of two (2) drops per second.

Having available the empirical tests of Dr. Albert Atterberg, which enable the determination of the plastic limit and liquid limit, it is possible to determine the magnitude of the moisture content range through which a soil is in the plastic state. This range of moisture content is the Plasticity Index (PI):

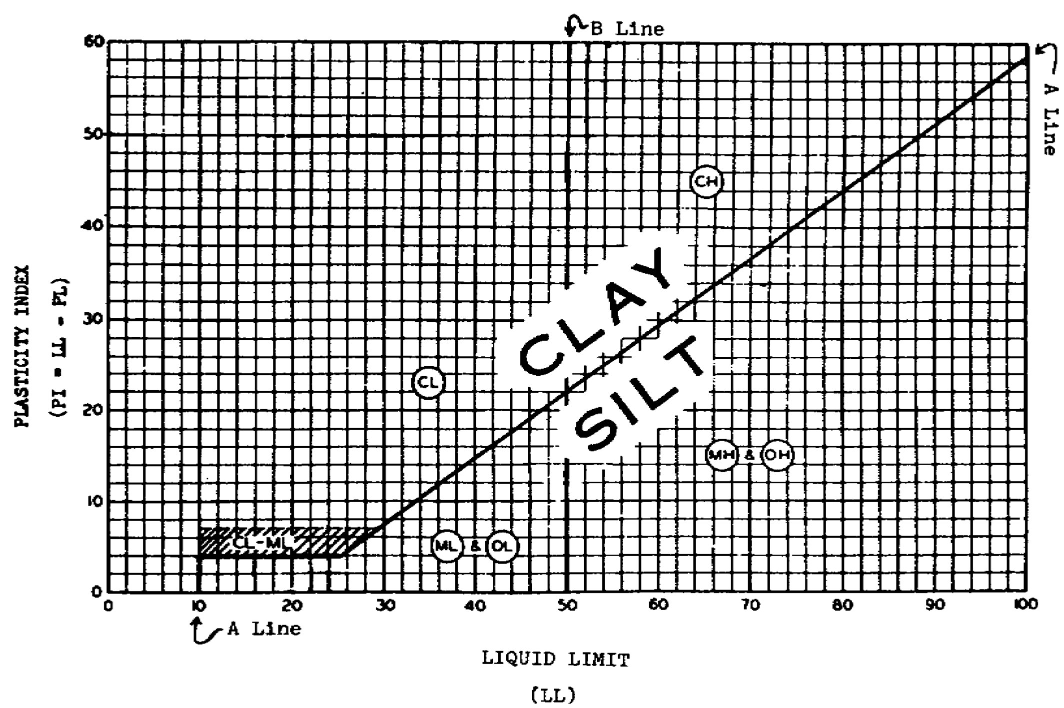
Plasticity Index	=	Liquid Limit	-	Plastic Limit
PI	=	LL	-	PL

If a soil then has a liquid limit of 25 and a plastic limit of 10, its plasticity index would be 15. In practice, engineers use the plasticity index coupled with the liquid limit as indexes to the properties of soil. Since clay is the material which causes a soil to be plastic, it would be expected that a fine soil mixture that is predominantly clay would have a larger plasticity index than a mixture which is predominantly silt or fine sand. The former also would be more likely to produce greater volume changes with varying moisture contents than the more "lean" mixture of low plasticity. A nonplastic soil (PI =), on the other hand, would probably be even less affected by moisture than the "lean" soil of low plasticity.

THE CASAGRANDE PLASTICITY CHART

The Casagrande Plasticity Chart is made by plotting the plasticity index versus the liquid limit. The Plasticity Chart (Figure 11) will provide you with a method for determining the type of fines.

FIGURE 11. PLASTICITY CHART



The A-line on the Plasticity Chart separates the clays from the silts. Any material whose values of PI vs. LL plot on the A-line or above will be classi-

fied as clay. And any material whose values of PI vs. LL plot below the A-line will be classified as silt. Materials whose limits plot within the cross-hatched area will exhibit both clayey and silty characteristics and therefore will be dually classified.

The B-line, of LL = 50 percent, separates the <u>high compressible</u> from the low <u>compressible</u> fine-grained soils. If the limits plot on the B-line or the right, the material will be high compressible. If the limits plot to the left of the B-line, the material will be classified as low compressible.

The amount of compressibility is an engineering characteristic which is critical to construction of roads and airfields. Dense plastic soils, for example, having a high water content are subject to compression and rebound under wheel load. Where this type of soil is encountered, steps must be taken to stabilize it. These procedures will be covered later in this subcourse.

SUMMARY

The soil characteristics determine its suitability to serve some intended purpose. Generally, a dense soil withstands greater applied loads (has greater <u>bearing capacity</u>) than a loose soil. Particle size has a relation to this capacity. From empirical tests, it has been found that well-graded, coarse grained soils generally can be compacted to a greater density than fine grained soils, because the smaller particles tend to fill the spaces between the larger ones.

The shape of the grains also affects the bearing capacity. Angular particles tend to interlock and form a denser mass and are more stable than the rounded particles which can roll or slide past one another. Poorly-graded soils with their lack of one or more sizes leave more or greater voids and therefore are a less dense mass. Moisture content and the consistency limits also determine the soil's suitability. A coarse-grained sandy or gravelly soil generally has good drainage characteristics and may be used in its natural state. A fine grained clayey soil with a high plasticity index may require considerable treatment especially if used in a moist location.

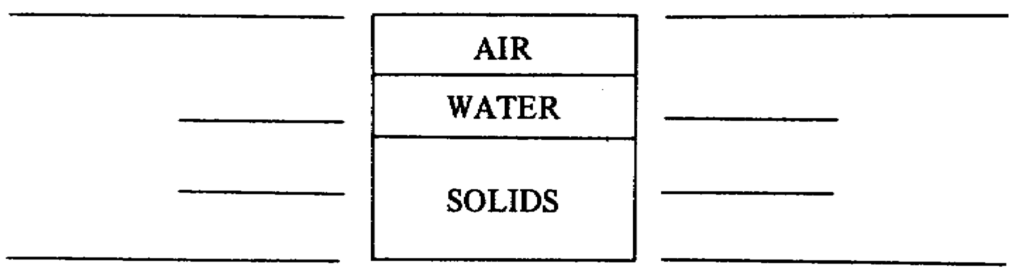
PRACTICE EXERCISE FOR LESSON 1

Instructions

Check your understanding of Lesson 1 by completing the practice exercise. There is only one correct answer to each question. Try to answer all of the questions without referring to the lesson materials.

When you have completed all of the questions, turn the page and check your answers against the correct responses. Each correct response is referenced to specific portions of the lesson material so that you can review any questions you have missed or do not understand, before continuing to the next lesson.

1. Using this drawing of a volume of soil, label the weight and volume proportions.



2. W_T = __________ + __________

3. V_T = __________ + __________ + __________

4. Some of the physical properties which determine a soil's engineering characteristics are moisture, gradation, particle grain size, specific gravity, and __________.

5. Gap-graded soils are weaker than well-graded soils because the voids between the particles are larger.

   a. True
   b. False

6. Cobbles are soil grains larger than three inches. Soil grains retained in the #4 sieve are called __________.

7. A "fat soil" will probably have to be treated for use in construction because

   a. it drains water too quickly.
   b. moisture causes it to lose strength.
   c. the rounded particles slip by one another and reduce the soil's resistance to penetration.
   d. its specific gravity is too low.

Lesson 1/Practice Exercise

Use the Grain Size Distribution Graph (next page) to answer the following questions:

8. What are the percentages of distribution?
   a. Gravel = ____________________
   b. Sand = ____________________
   c. Fines = ____________________

9. What is the predominant material?

10. Which set of data is correct?

a.	D_{60} = 1.5	b.	D_{60} = 1.1	c.	D_{60} =2.7
	D_{30} = 1.3		D_{30} = 2.7		D_{30} = 1.1
	D_{10} =.24		D_{10} = 2.0		D_{10} = .2

11. What is the Coefficient of Uniformity? C_u = _______________.

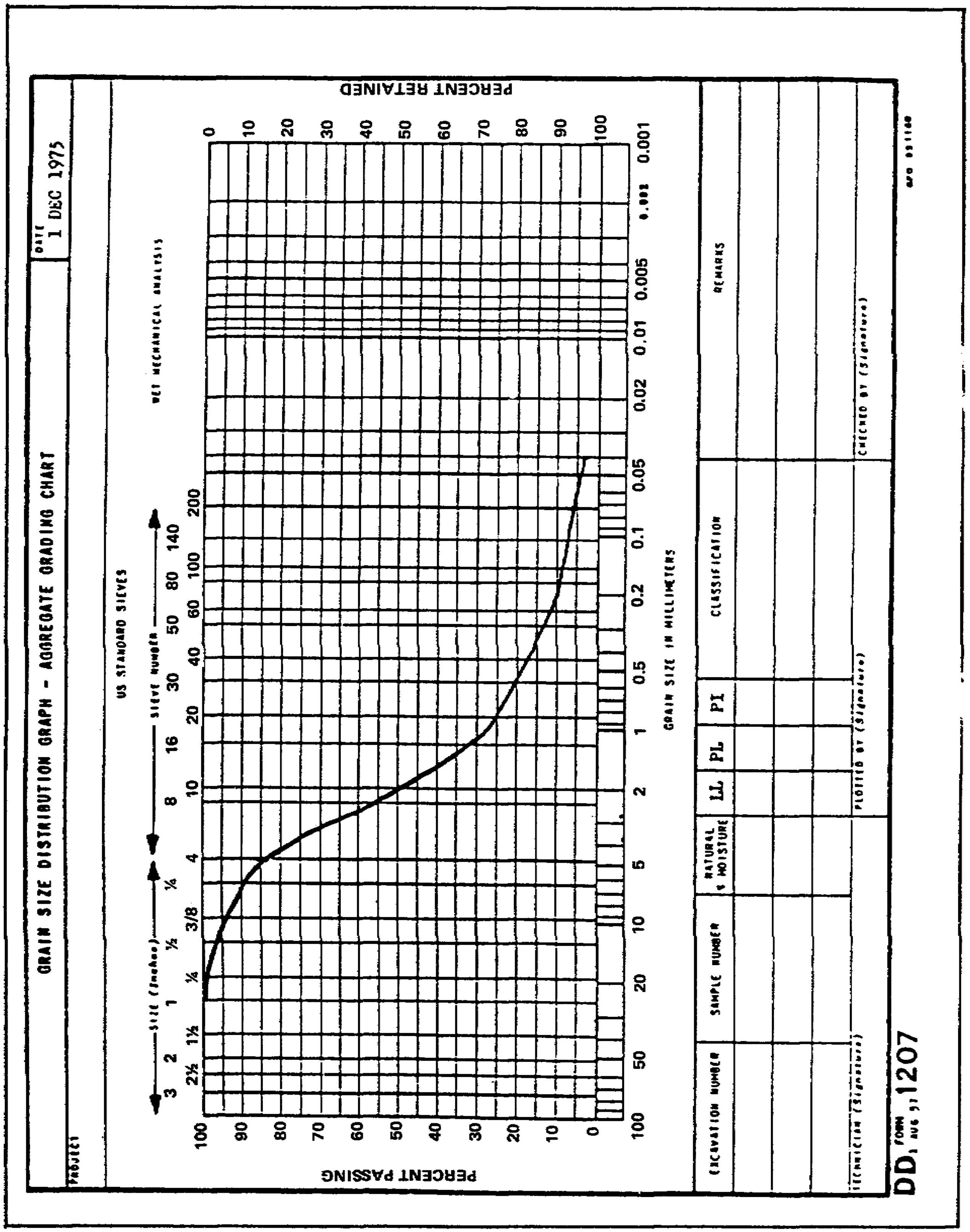
12. What is the Coefficient of Curvature? C_c = _______________.

13. What is the gradation?
   a. poorly-graded; gap-graded
   b. poorly-graded; uniformly graded
   c. well-graded

14. If the soil contains so much moisture that it is at the liquid state, the material
   a. crumbles under pressure.
   b. may be rolled into a 1/8-inch thread before crumbling.
   c. deforms under pressure and remains in that form.
   d. flows under its own weight.

15. Using the Atterberg limits to determine moisture content if you take a sample and roll it into a 1/8-inch diameter thread one time before it breaks, that soil sample is said to be
   a. highly compressible
   b. fat
   c. at the plastic limit
   d. at the liquid limit

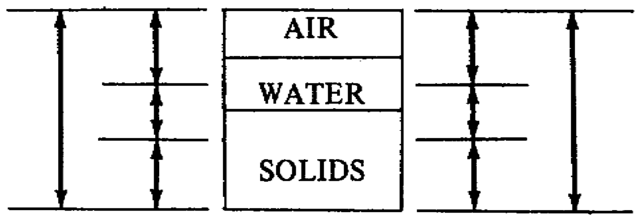
16. When a soil plots in the box at the base of the A-line on the Casagrande Plasticity Chart, the soil is
   a. high compressible clay
   b. either clay or silt
   c. primarily silt
   d. impossible to determine


GRAIN SIZE DISTRIBUTION GRAPH - AGGREGATE GRADING CHART
PROJECT
DATE
1 DEC 1975
US STANDARD SIEVES
SIZE (Inches)
SIEVE NUMBER
WET MECHANICAL ANALYSIS
3 2½ 2 1½ 1 ¾ ½ 3/8 ¼
4 8 10 16 20 30 40 50 60 80 100 140 200
PERCENT PASSING
PERCENT RETAINED
GRAIN SIZE IN MILLIMETERS
100 50 20 10 5 2 1 0.5 0.2 0.1 0.05 0.02 0.01 0.005 0.001
EXCAVATION NUMBER
SAMPLE NUMBER
NATURAL % MOISTURE
LL
PL
PI
CLASSIFICATION
REMARKS
TECHNICIAN (Signature)
PLOTTED BY (Signature)
CHECKED BY (Signature)
DD FORM 1207

Lesson 1/Practice Exercise Answers

ANSWER SHEET FOR PRACTICE EXERCISE

Lesson 1

		Learning Event
1.		1
2.	$W_T = W_w \quad W_s$	1
3.	$V_T = V_s + V_w + V_2$	1
4.	Plasticity	1
5.	True	1
6.	Gravel	1
7.	Moisture causes it to lose strength	1
8.	Gravel = 16 percent Sand = 78 percent Fines = 6 percent	2
9.	Sand	2
10.	c	2
11.	$D_{60} = 2.7$ $D_{10} = .2$ $C_u = D_{60}/D_{10} = 2.7/.2 = 13.5$	2
12.	$D_{30} = 1.1$	2
	$C_c = (D_{30})^2/D_{60} \times D_{10} = 1.21/.54 = 2.24$	2
13.	c	2
14.	d	3

15.	c	3
16.	b	3

Lesson 2
SOIL CLASSIFICATION AND FIELD IDENTIFICATION PROCEDURES

TASK: Classify Soils Using the Unified Soil Classification System and Field Identification Procedures.

CONDITIONS: Given this subcourse, a No. 2 pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by responding correctly to 75% of the examination questions.

CREDIT HOURS: 2

REFERENCE: FM 5-530

Learning Event 1
IDENTIFY SYMBOLS USED IN USCS

This learning event will introduce you to the Unified Soil Classification System (USCS) which allows you to apply a short lettered symbol to a soil for the purposes of communication and identification of the engineering characteristics.

CLASSIFICATION SYSTEM

In the Unified Soil Classification System, all soils are divided into three major categories:

- Coarse-grained soils.
- Fine-grained soils.
- Organic soils.

Coarse-grained and fine-grained soils are differentiated by grain size. Organic soils are identified by the presence of large amounts of organic material.

The Unified Soil Classification System further divides soils which have been classified into the major soil categories by using arbitrary letter symbols consisting of two letters. For example, the letters for sand, silt, and clay are S, M, and C, respectively, and the symbol for a soil which meets the criteria for a clayey sand is designated by SC. In the case of borderline soils which possess characteristics of two groups and cannot be classified by a single symbol, it may be necessary to use four letters such as SM-SC which would describe a sand which contains appreciable amounts of fines on the borderline classification for silt and clay. After the physical characteristics of a soil have been determined by use of the appropriate tests and calculations described in Lesson 1, these characteristics are used to classify the soil. The criteria for identification are presented in the form of a job aid in Table 2 later in this lesson.

PRIMARY AND SECONDARY LETTERS

The Unified Soil Classification System uses a system of two letter abbreviations to describe the soil.

PRIMARY (lst letter).................................... identifies the predominant soil fraction

SECONDARY (2nd Letter).......................... an adjective further describing the characteristics of the predominant fraction

The percentages of gravel, sand, and fines provide information necessary to choose the primary letter. Symbols used as primary letters (used for describing the predominant soil fraction) are:

- G - Gravel
- S - Sand
- C -Clay
- M - Silt (M stands for Mo, the Swedish word for silt)
- O - Organic

Symbols used as secondary letters in the USCS are shown in Table 2.

TABLE 2. USCS SYMBOLS	
W - Well Graded P - Poorly Graded	Used to describe sands and gravels containing less than 12 percent fines.
M - Silty Fines C - Clayey Fines	Used with sands and gravels containing more than 5 percent but less than or equal to 50 percent fines.
L - Low Compressibility (LL $<$ 50 percent H - High Compressibility (LL $\geq$ 50 percent)	Used to describe fine grained soils (silts, clays, organics)

All fine grained soils (more than 50 percent fines) will have secondary letters of L or H.

The primary letters of G (gravel) and S (sand) are used only for soils with less than or equal to 50 percent fines.

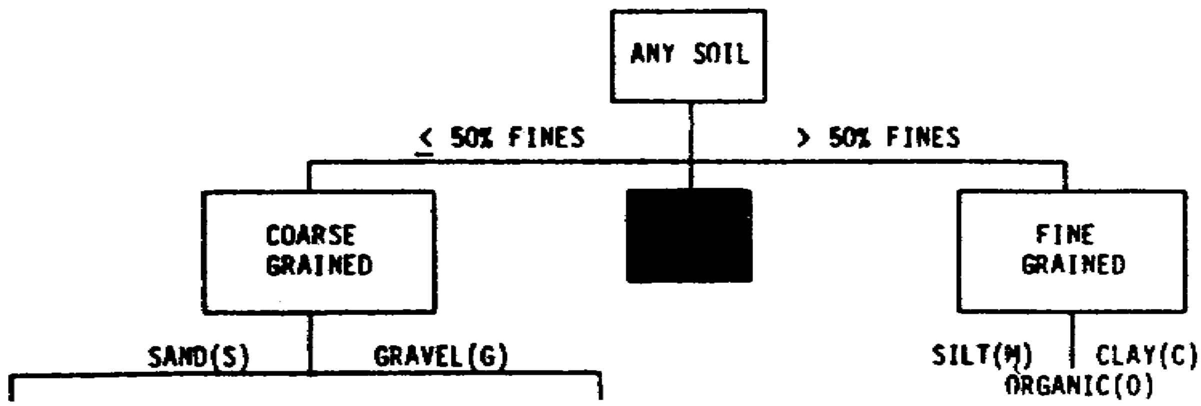
The symbol used depends upon which coarse-grained fraction is dominant. For example, a coarse-grained soil (less than or equal to 50 percent fines) having more gravel than sand would have the primary letter for the classification as G.

M (silt), C (clay), and O (organic) are used as primary letters only with fine-grained soils (more than 50 percent fines). M (silty fines) and C (clayey fines) are used as secondary letters in a coarse-grained soil to describe the relative plasticity of the fines. As a result, non-plastic fines would be indicated by a secondary letter of M for silty fines.

L (low compressible) and H (high compressible) are only used as secondary letters. They describe the compressibility of a fine grained soil (more than 50 percent fines). For example, a fine-grained soil whose liquid limit is 65 percent would have a secondary letter of H.

A USCS chart built from the information just given would look like the chart in Figure 12.

FIGURE 12. SOIL CLASSIFICATION CHART



Coarse Grained Soils with Greater than 12 Percent Fines.

Consider what happens when we increase the amount of fines. If we increase the amount of fines to <u>greater than 12 percent</u>, construction characteristics of the sample become dependent more on the type of fines than on gradation, and our classification system reflects this transition. When a coarse-grained (less than or equal to 50 percent fines) soil has greater than 12 percent fines, the soil is described by a secondary letter of M or C indicating the type of fines. To determine the type of fines, you need to plot the plasticity and compressibility on the plasticity chart.

The possible classifications of soils with greater than 12 percent but less than or equal to 50 percent fines are:

- GM
- GC
- SM
- SC

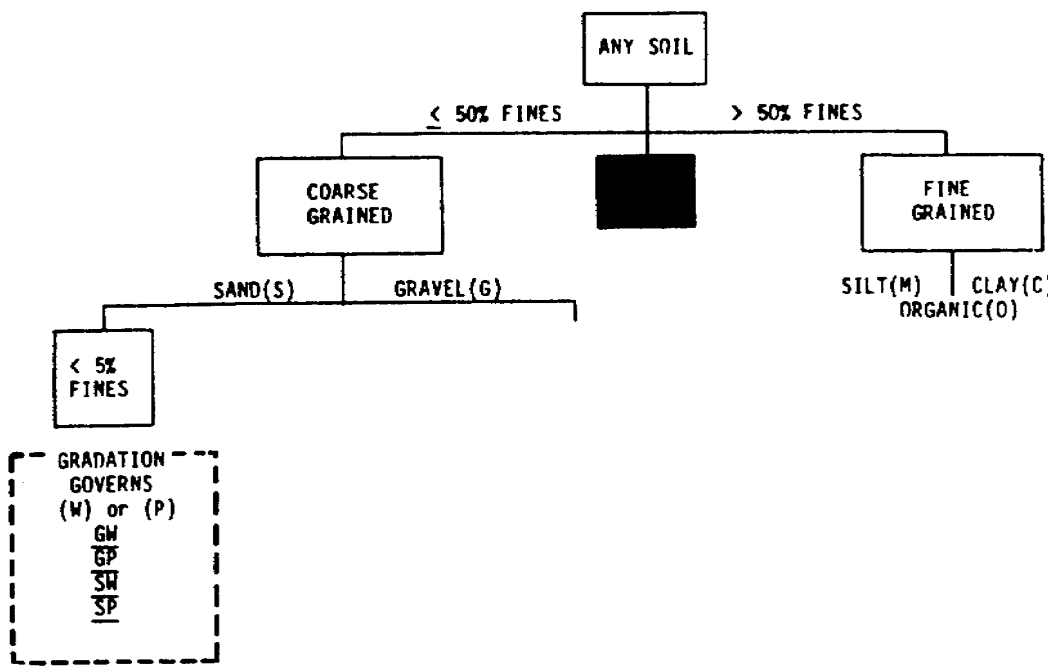
The dual classifications are GM-GC and SM-SC.

Learning Event 2
CLASSIFY COARSE- AND FINE-GRAINED SOILS

Coarse-grained Soils with Less than 5 Percent Fines

If a coarse-grained soil has less than 5 percent fines, the fines will not significantly affect the construction properties of the soil. Soils with less than 5 percent fines are, therefore, classified according to the gradation of the coarse fraction (Figure 13).

FIGURE 13. SOIL CLASSIFICATION CHART



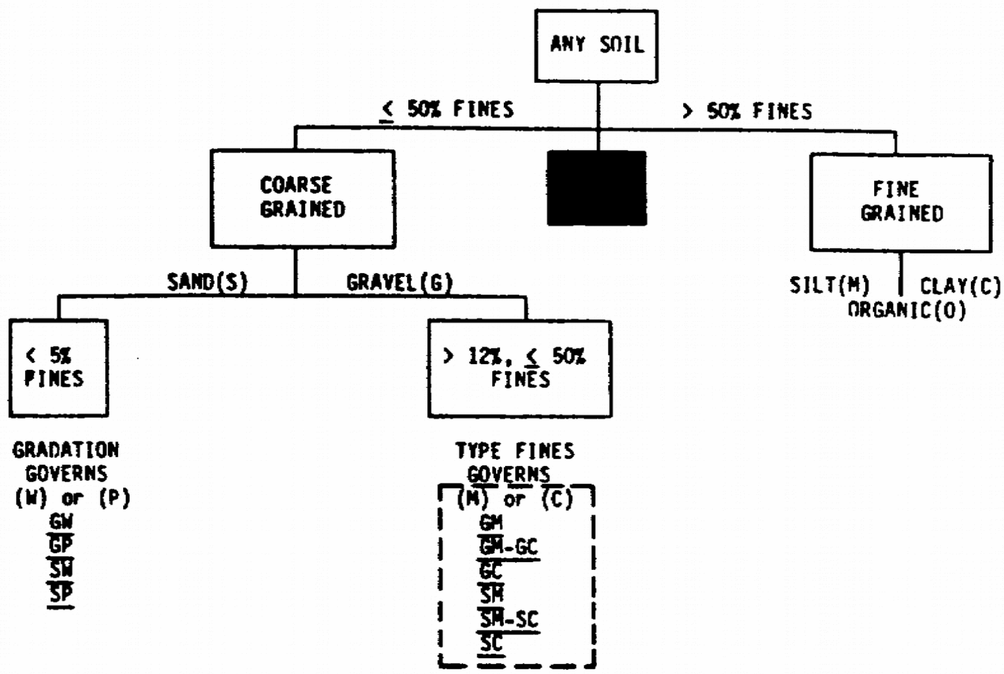
The possible classifications for a coarse-grained soil with less than 5 percent fines are:

- GW (Well-Graded Gravel)
- GP (Poorly-Graded Gravel)
- SW (Well-Graded Sand)
- SP (Poorly-Graded Sand)

Remember that any point falling in the box on the bottom of the A-line on the Casagrande Plasticity Chart cannot be classified solely as either silt or clay. It is classified as a combination of both. The first and third letter of

the classification is the primary letter of the symbol. The second letter is always M and the fourth letter is always C. Figure 14 covers coarse-grained soils with less than 5 percent fines and greater than 12 percent fines.

FIGURE 14. SOIL CLASSIFICATION CHART



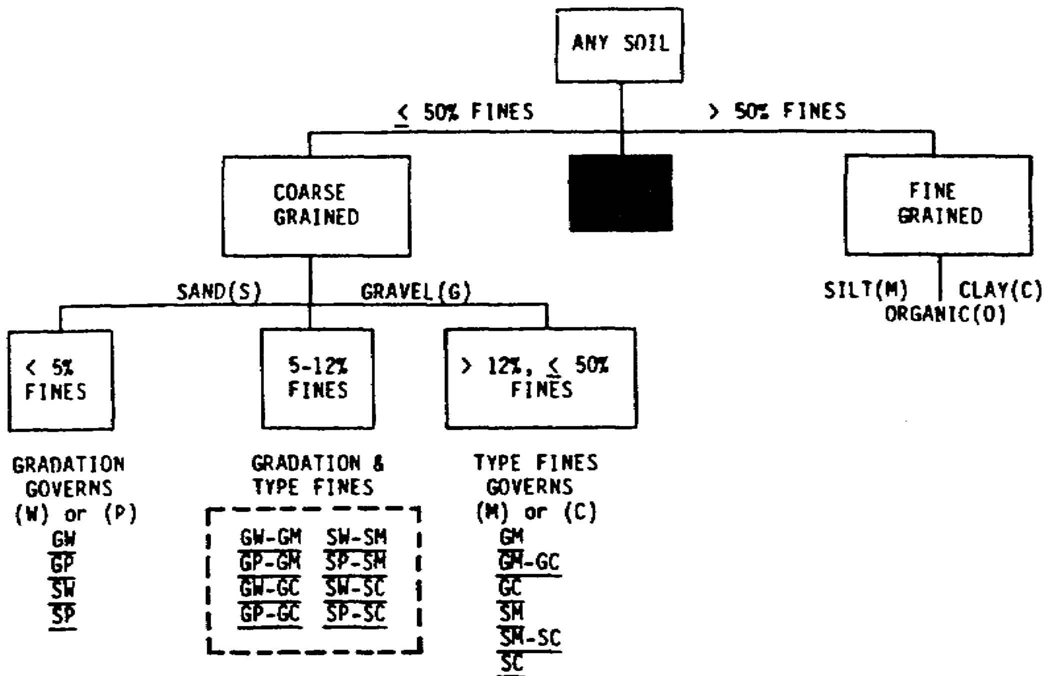
Coarse-grained Soil with Fines from 5 to 12 Percent

Soils with 5 percent or more fines but with less than or equal to 12 percent fines can be well-graded (W) or poorly-graded (P) but, the amount of fines are enough to be significant when considering the soil for use as a construction material. Therefore, when a soil has 5 - 12 percent fines we use a dual classification to reflect both the gradation and type of fines.

The first and third letters of the dual classification are always the same and are always the primary letter of classification. The second letter describes the gradation characteristics of the soil and the fourth letter indicates the type of fines.

The possible classifications for soils of this type are shown in Figure 15.

FIGURE 15. SOIL CLASSIFICATION CHART



Fine Grained Soils

You will recall that since we have three types of fine-grained soil-silt, clay, and organic-our primary letters for fine-grained material will be either:

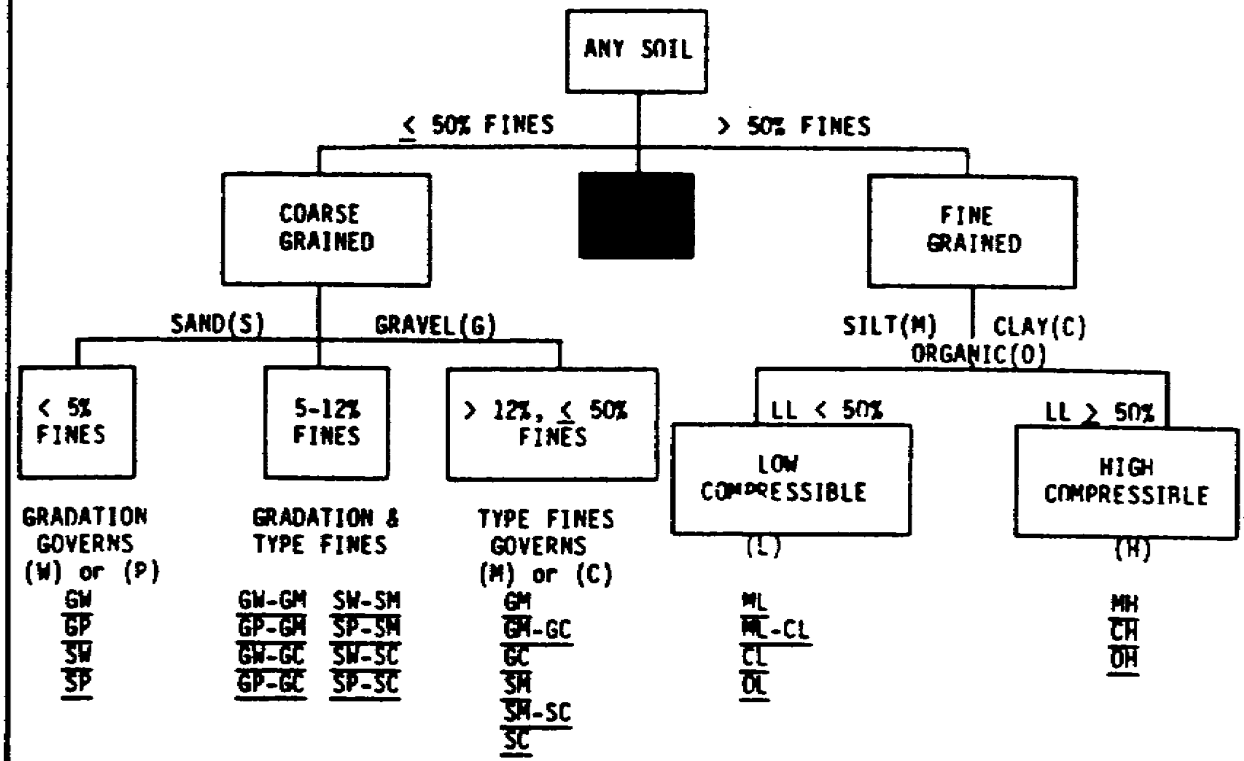
- M - Silt
- C - Clay
- O - Organic

The plasticity characteristics of organic fines plot below the A-line of the plasticity chart as do silt fines. Organic fines can be differentiated from silt fines by their dark color and their musty odor. For example, a dark, musty soil whose LL is 52 percent and whose PI is 10 percent would have a primary letter of O for organic.

For fine-gained soils we further identify the soil by its compressibility. Soils with a Liquid Limit less than 50 percent are low compressible (L) and soils

with a Liquid Limit grater than or equal to 50 percent are <u>h</u>igh compressible (H).

FIGURE 16. SOIL CLASSIFICATION CHART



For a low compressible fine-grained soil the possible classifications are shown in Figure 16 above:

- ML
- CL
- OL
- ML-CL

The high compressible soils have an LL equal to or above 50 percent. Their possible classifications are shown in Figure 16 above:

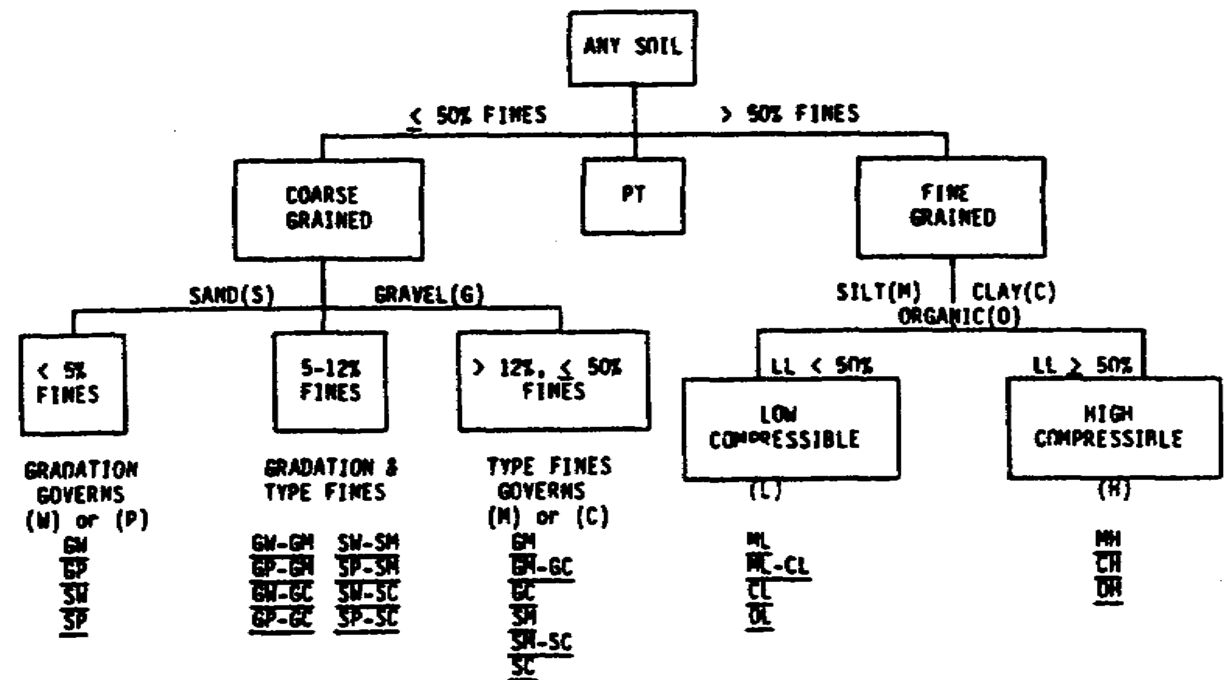
- MH
- CH
- OH

The only classification we have left is the symbol for <u>peat</u> which is <u>PT</u>. Peat is a fibrous organic material such as peat moss. It is completely unsuitable for construction and is identified visually.

Figure 17, following, shows the complete classification chart. Notice that the soil classifications are arranged in descending order of construction durability from left to right and from top to bottom (excluding PT). That is, the very best construction material is GS soil and the very worst is OH, generally speaking. For example, if you were given a choice between a GP-GM soil and a SC soil for construction purposes you could determine that GP-GM was better because of its placement on the USCS table.

Figure 17 has been designed as a job aid to help you classify soils. Use it when you do the practice exercise.

FIGURE 17. SOIL CLASSIFICATION CHART



Learning Event 3
USE VISUAL EXAMINATION PROCEDURES TO CLASSIFY SOILS

It is not uncommon for the military engineer to find himself/herself in the field without laboratory soil testing facilities. Even where laboratory tests are to follow, field identification tests must be made during the soil exploration to distinguish between the different soil types encountered. In this way duplication of samples for laboratory testing will be held to a minimum. Several simple tests that you may use in field identification are described in this lesson. Each test requires a minimum of time and equipment, although you will seldom need all of them to identify any given sample. Using these tests, you can estimate the soil properties and classify the materials. You should recognize such classification as an approximation, since even experienced personnel have difficulty estimating detailed soil properties with a high degree of accuracy. The material which follows is intended as an aid in the identification and classification of soils according to the unique Soil Classification System.

The experienced engineer can get a lot of information from a visual examination. It is possible to determine the color, grain size, and grain shape of the coarse-grained portion of a soil, and estimate the grain size distribution. To observe these properties, a sample of the material is first dried and then spread on a flat surface.

COLOR

In field soil surveys, color is often helpful in distinguishing between various soil strata. Color is also useful for identifying soil types. Since the color of a soil often varies with its moisture content, you must always record the condition of the soil when you determine color. There is generally more contrast in these colors when the soil is in a moist condition, with all the colors becoming lighter as the moisture contents are reduced. In fine-grained soils, certain dark or drab shades of gray or brown, including most black colors, are indicative of organic colloidal matter (OL, OH). In contrast, clean and bright looking colors, including medium and light gray, olive green, brown, yellow, and white generally are associated with inorganic soils. Soil color also may indicate the presence of certain chemicals. Red, yellow, and yellowish brown soil colors may be a result of the presence of iron oxides. White to pinkish colors may indicate presence of considerable silica, calcium carbonate, or aluminum compounds in some cases. Grayish blue, and gray and yellow mottled colors frequently indicate poor drainage.

GRAIN SIZE

The maximum particle size should always be estimated for each sample considered, thereby establishing the upper limit of the grain size distribution curve for that sample. To aid in determining something about the lower limit of the grain size distribution, it is useful to know that the naked eye can normally distinguish the individual grains of soil down to about 0.07 millimeters.

This means that all of the particles in the gravel and sand ranges are visible to the naked eye. All of the silt particles and all of the clay particles are smaller than this size and are therefore invisible to the naked eye. Material smaller than 0.07 millimeters will pass the #200 sieve.

GRAIN SIZE DISTRIBUTION

The laboratory mechanical analysis must be performed whenever the grain size distribution must be determined accurately. However, an approximation of the grain size distribution can be made by visual inspection. Spread a portion of the dry sample on the flat surface; then, using your hands or a piece of paper, attempt to separate the material into its various grain size components. By this method, the gravel particles and some of the sand particles can be separated from the remainder. This will at least give the observer an opportunity to estimate whether the total sample is to be considered coarse-grained or fine-grained, depending on whether or not more than 50 percent of the material would pass the #200 sieve.

Coarse-grained Soils

If the material is believed to be coarse-grained, then there is less than 5 percent passing the #200 sieve; and, the fines are nonplastic. If both these criteria can be satisfied and there appears to be a good representation of all grain sizes from largest to smallest, the material may be said to be well-graded (GW or SW). If any intermediate sizes appear to be missing, or if there is too much of any one size, then the material is poorly graded (GP or SP).

Fine-grained Soils

Estimating the grain size distribution of a sample using no equipment at all is probably the most difficult part of field identification. It depends to a great extent on the experience of the individual making the estimate. A better approximation of the relative proportions of the components of the finer soil fraction may sometimes be obtained by shaking a portion of this sample into a jar of water and then allowing the material to settle to the bottom. The material will settle in layers; the gravel and coarse sand particles settling out almost immediately, the fine sand particles within a minute, the silt particles requiring as much as an hour, and the clay particles remaining in suspension indefinitely, or until the water is clear. In using this method, keep in mind that the gravel and sand will settle into a much more dense formation than will either the silt or clay.

GRAIN SHAPE

The grain shape of the sand and gravel particles can be determined by close examination of the individual grains. The grain shape affects the stability of the soil. Remember that increased resistance to displacement is found in the more irregular particles. A material whose grains are rounded has only

the friction between the surfaces of the particles to help hold them in place. In an angular material, the friction is increased by the roughness of the surface and the area of contact. In action, an interlocking action is developed between the angular particles which gives a much greater stability than friction alone.

UNDISTURBED SOIL PROPERTIES

A complete description of a soil includes prominent characteristics of the undisturbed materials. The aggregate properties of sand and gravel are described qualitatively by the terms loose, medium, and dense, while those of clays are described by hard, stiff, medium, and soft. These characteristics usually are evaluated on the basis of several factors, including the relative ease or difficulty of advancing the drilling and sampling tools and the consistency of the samples. In soils that are described as soft, it should also be indicated whether the material is loose and compressible, as in an area under cultivation, or spongy or elastic, as in highly organic soils. (Moisture conditions will influence these characteristics and should be included in the report.)

Learning Event 4
CONDUCT A FIELD TEST FOR #40 SIEVE MATERIAL

Tests for identification of the fine-grained portion of any soil are performed on the portion of the material which passes a #40 sieve. This is the same soil fraction used in the laboratory for Atterberg limits tests, such as plasticity.

Some or all of the following tests produce observations that pertain to the Unified Soil Classification System. Such tests as are appropriate to the given soil sample should be made. Some tests appear to yield duplicate results. The purpose of these tests is to get the best possible identification in the field. Thus, if a simple visual examination will define the soil type, only one or two of the other tests have to be made to verify or check the identification. On the other hand, when the results from a test are inconclusive, some of the similar tests should be tried to establish the best identification.

ODOR TEST

Organic soils of the OL and OH groups usually have a distinctive, musty, slightly offensive odor which, with experience, can be used as an aid in their identification. This odor is especially apparent from fresh samples. It is gradually reduced by exposure to air, but can again be made more pronounced by heating a wet sample.

DRY STRENGTH TEST

The dry strength, or breaking test, as well as the roll test and the ribbon test, is used to measure the cohesive and plastic characteristics of the soil. The test normally is made on a small pat of soil about 1/2 inch thick and about 1 1/2 inches in diameter. The pat is prepared by molding a portion of the soil in the wet plastic state into the size and shape desired and then allowing the pat to dry completely. Samples may be tested for dry strength in their natural condition as they are found in the field, but much reliance should not be given to such tests because of the variations that exist in the drying conditions under field conditions. Such a test may be used as an approximation, however, and verified later by a carefully prepared sample.

After the prepared sample is thoroughly dry, attempt to break it using the thumb and forefingers of both hands, as shown in Figure 18. If it can be broken, try to powder it by rubbing it with the thumb and fingers of one hand.

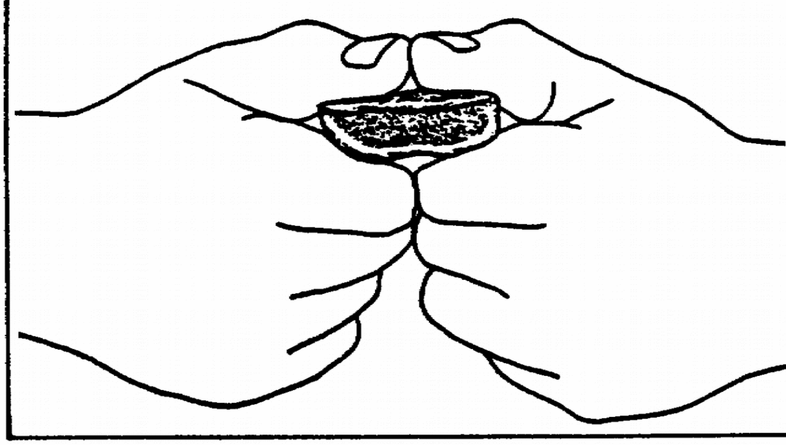
Typical Reactions

These are the typical reactions that are obtained in this test for various types of soils:

- Very Highly Plastic Soils (CH) have very high strength. Samples cannot be broken or powdered by use of finger pressure.

- Highly Plastic Soils (CH) have very high strength. Samples can be broken with great effort, but cannot be powdered.
- Medium Plastic Soils (CL) have medium strength. Sample can be broken and powdered with some effort.
- Slightly Plastic Soils (ML, MH, or CL) have low strength. Samples can be broken quite easily and powdered readily.
- Non-plastic Soils (ML or MH) have very little or no strength. Samples crumble and powder on being picked up in the hands.

FIGURE 18. DRY STRENGTH TEST



Precautions

The test described above is one of the best for distinguishing plastic clays and non-plastic silts or fine sands. However, a word of caution is appropriate. Dry pats of highly plastic clays quite often display shrinkage cracks. To break the sample along such a crack will give an indication of only a very small part of the true strength of the soil. It is important to distinguish between a break along such a crack, and a clean, fresh break that indicates the true dry strength of the soil.

FEEL TEST

The feel test is a general purpose test, and one that requires considerable experience and practice before reliable results can be obtained. Some of the following characteristics can be readily estimated by proper use of this test.

Moisture Content

The natural moisture content of a soil is an indicator of the drainage characteristics, nearness to water table, or other factors which may affect this property. A sample of undisturbed soil is tested by squeezing it between the thumb and forefinger to determine its consistency. This consistency is

described by such terms as hard, stiff, brittle, friable, sticky, plastic, or soft. The soil is then remolded by working it in the hands, and changes, if any, are observed. By this test, the natural water content is estimated relative to the liquid or plastic limit of the soil. Clays which turn almost liquid on remolding are probably near or above the liquid limit. If the clay remains stiff, and crumbles upon being remolded, the natural water content is below the plastic limit.

Texture

The term texture refers to the degree of fineness and uniformity. It is described by such expressions as floury, smooth, gritty, or sharp, depending on the sensation produced by rubbing the soil between the fingers. Sensitivity may be increased by rubbing some of the material on a more tender skin area such as the wrist. Fine sand will feel gritty. Typical dry silts will dust readily, and feel relatively soft and silky to the touch. Clay soils are powdered only with difficulty but become smooth and gritless like flour.

SHINE TEST

The shine test is another means of measuring the plasticity characteristics of clays. A slightly moist or dry piece of highly plastic clay will give a definite shine when rubbed with a fingernail, a pocket knife blade, or any smooth metal surface. On the other hand, lean clay will not display any shine, but will remain dull.

THREAD TEST

The roll or thread test uses a soil sample prepared by adding water until the moisture content is such that the sample may be easily remolded without sticking to the fingers. This is sometimes referred to as being just below the “sticky limit.” Using a nonabsorbent surface, such as glass, this sample is rolled rather rapidly into a thread approximately 1/8 inch in diameter.

If a moist soil can be rolled into such a thread at some moisture content, it is said to have some plasticity. Materials which cannot be rolled in this manner are nonplastic, or have very low plasticity. Figure 19 shows the roll test being performed.

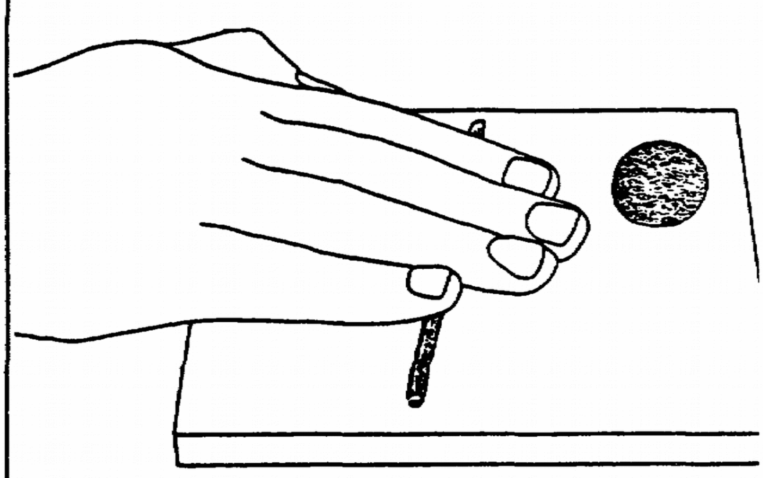
Typical Reactions

After reaching the plastic limit, the degree of plasticity may be one of the choices below:

- <u>High plasticity</u> (CH). The soil may be remolded into a ball and the ball deformed under extreme pressure by the fingers without cracking or crumbling.
- <u>Medium Plasticity</u> (CL). The soil may be remolded into a ball, but the ball will crack and easily crumble under pressure of the fingers.

- Low Plasticity (CL, ML, or MH). The soil cannot be lumped together into a ball without completely breaking up.
- Organic Materials (OL or OH). Soils containing organic materials or mica particles will form soft spongy threads or balls when remolded.
- Nonplastic Soils (ML or MH). These cannot be rolled into a thread at any moisture content.

FIGURE 19. THREAD TEST



Description of Cohesiveness

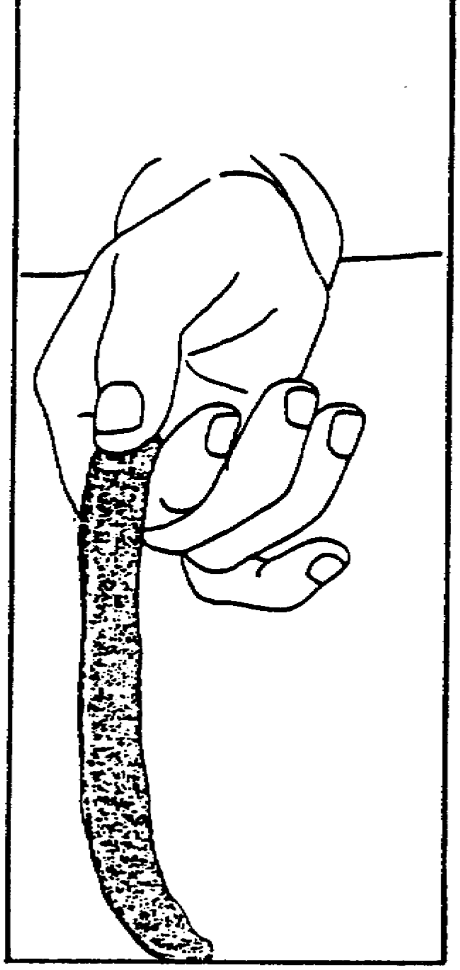
From this test, the cohesiveness of the material near the plastic limit may also be described as weak, firm, or tough. The higher the position of a soil on the plasticity chart, the stiffer are the threads as they dry out-and the tougher are the lumps if the soil is remolded after rolling.

RIBBON TEST

The sample prepared for use in this test should have a moisture content slightly below the "sticky limit." The sticky limit is the lowest water content at which the soil will adhere to a metal tool. Using this material, form a roll of soil about 1/2 to 3/4 inch in diameter and about 3 to 5 inches long. Place the material in the palm of the hand and, starting with one end, flatten the roll, forming a ribbon 1/8 to 1/4 inch thick by squeezing it between the thumb and forefinger. The sample should be handled carefully to form the maximum length of ribbon that can be supported by the cohesive properties of the material. If the soil sample holds together for a length of 8 to 10 inches without breaking, the material is then considered to be both highly plastic

and highly compressive (CH). If the soil cannot be ribboned, it is nonplastic (ML or MH). If it can be ribboned only with difficulty into short lengths, the soil is considered to have low plasticity (CL). The roll test and the ribbon test complement each other in giving a clearer picture of the degree of plasticity of soil. Figure 20 illustrates how the ribbon test is performed.

FIGURE 20. RIBBON TEST



BITE OR GRIT TEST

The bite and grit test is a quick and useful method of identifying sand, silt, or clay. In this test, a small pinch of the soil material is ground lightly between the teeth and the soils identified as follows.

Sandy Soils

The sharp hard particles of sand will grate very harshly between the teeth and will be highly objectionable. This is true even of the fine sand.

Silty Soils

The silt grains are so much smaller than sand grains that they do not feel nearly so harsh between the teeth, and are not particularly gritty although their presence is still easily detected.

Clayey Soils

The clay grains are not at all gritty, but feel smooth and powdery like flour between the teeth. Dry lumps of clayey soils will stick when lightly touched with the tongue.

WET SHAKING TEST

Like all the other tests described in this part the wet shaking test is performed only on the material passing the #40 sieve. For this test, enough material to form a ball of material about 3/4 inch in diameter is moistened with water. This sample should be just wet enough that the soil will not stick to the fingers upon remolding or just below the sticky limit.

Place the soil in the palm of the hand and shake vigorously. This is done by jarring the hand on the table or some other firm object, or by jarring it against the other hand. The soil is said to have given a reaction to this test when, on shaking, water comes to the surface of the sample producing a smooth, shiny appearance. This appearance is frequently described as "livery." Then, squeeze the sample between the thumb and forefinger of the other hand. The surface water will quickly disappear and the surface will become dull. The material will become firm and resist deformation. Cracks will occur as pressure is continued, with the sample finally crumbling like a brittle material. The vibration caused by the shaking of the soil sample tends to reorient the soil grains, decrease the voids, and force water, which had been within these voids, to the surface. Pressing the sample between the fingers tends to disarrange the soil grains and increase the voids space, and the water is drawn into the soil. If the water content is still adequate, shaking the broken pieces will cause them to liquefy again and flow together, and the complete cycle may be repeated. This process can occur only <u>when the soil grains are bulky and noncohesive</u>.

Typical Reactions

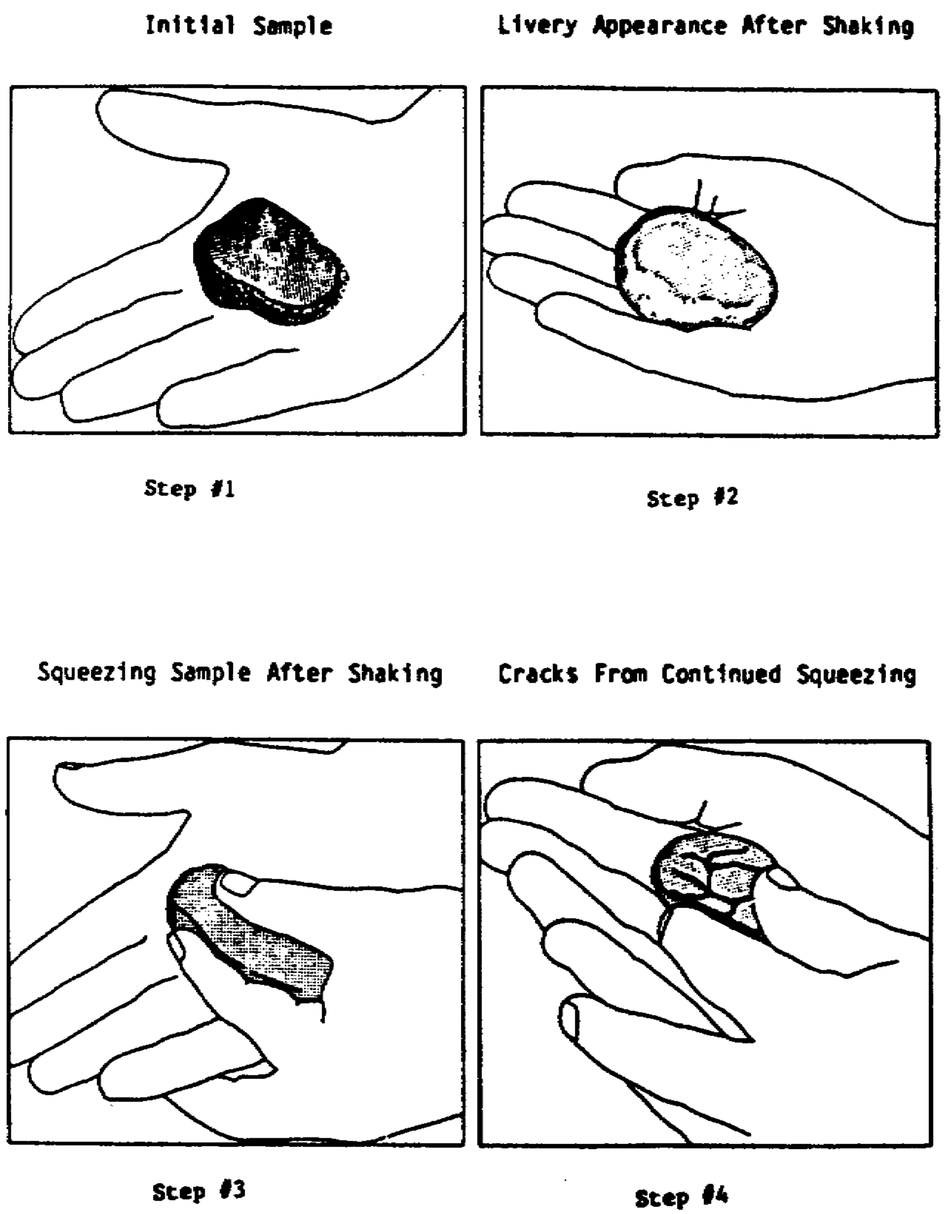
Very fine sands and silts fall into this category and are readily identified by the wet shaking test. Since it is rare that fine sands and silts occur without some amount of clay mixed with them, there are varying degrees of reaction to this test. Even a small amount of clay will tend to greatly retard this reaction. Some of the descriptive terms applied to the different rates of reaction to this test are as follows:

- <u>Sudden or Rapid</u>. A rapid reaction to the shaking test is typical of nonplastic, fine sands, and silts.

- Sluggish or Slow. A sluggish reaction indicates slight plasticity such as might be found from a test of some organic silts, or silts containing a small amount of clay.
- No reaction. Obtaining no reaction at all to this test does not indicate a complete absence of silt or fine sand.

Figure 21 shows four steps in the wet shaking test.

FIGURE 21. WET SHAKING TEST



Learning Event 5
IDENTIFY THREE TESTS FOR A HASTY CLASSIFICATION

With the standard methods of field identification supplemented with a few simplified field tests, you can obtain an approximate and hasty classification of almost any soil. The three simple or hasty tests outlined below will, for the most part, eliminate the need for specialized equipment such as sieves. The results of these tests, when used or supplemented with the results of the tests described in the previous learning events, will give at least a tentative classification to almost any soil. The schematic (Figure 17) may be used as a guide to the testing sequence in the process of assigning a symbol to a sample of soil.

SEDIMENTATION TEST

From the visual inspection test described earlier, it is relatively simple to approximate the comparative proportions of sand and gravel in a sample of soil by spreading a dry sample out on a flat surface, and separating the gravel particles by hand. Separating the fines from the sand particles is more difficult although just as important. Smaller particles will settle through water at a slower rate than large particles. Place a small amount of soil (such as a heaping tablespoon measure) in a transparent cup or jar. Cover the sample with about 5 inches of water, and agitate by stirring or shaking. The soil will be completely suspended in the water. With most cohesive soil you will have to break up the lumps of soil before adding the water. Do this by grinding the soil in a canteen cup with an improvised wood pestle. After the soil particles have been thoroughly dispersed in the water and then left, they will start to settle, beginning with the larger size particles, as indicated in Table 3.

TABLE 3. SETTLING TIMES FOR SMALL PARTICLES

Approximate Time of Settlement Through 5 Inches of Water	Grain Diameter	Differentiates
2 seconds	0.4 mm	Coarse Sand--Fine Sand
30 seconds	0.72 mm	Fine Sand--Coarse Silt
10 minutes	0.03 mm	Coarse Silt--Fine Silt
1 hour	0.01 mm	Fine Silt--Clay

You can perform the same test described above after separating out the #40 sieve soil fraction. Use a procedure similar to that outlined above except pour off the water within one or two seconds after completion of agitation. The suspended portion will then include the particles of the fine sand range.

A difficulty that you will encounter with many clay soils stems from the fact that the clay particles often form small lumps (flocculate) that will not break up in water. Usually this condition can be detected by examining the coarse fraction of the soil after several repetitions of the test. If substantial amounts of clay are still present, the sand will have a somewhat slippery feel and further mixing and grinding with a wood stick will be necessary to break up these lumps.

CAST TEST

The cast test refers to the strength of a moist soil sample when squeezed in the hand. It is used to indicate the approximate type and quantity of fines present in the sample. The correct amount of water to add to the soil must be estimated by trial and error. Generally stated, the maximum cohesion or attraction between the individual soil particles normally will occur when the soil is damp but not sticky. The test consists of compressing a handful of the moist soil into a ball or cigar-shaped cast and observing its ability to withstand handling without crumbling. While experience is desirable in making predictions based upon this test, Table 4 serves as a general guide of the behavior of different soil types when formed into a cast and tested.

TABLE 4. CAST TEST REACTIONS

Soil Type	Reaction to Handling
GP, SP, SW, GW	Cast crumbles when touched.
SM, SC	Cast withstands careful handling.
ML, MH	Cast can be handled freely.
CL, CH	Cast withstands rough handling.

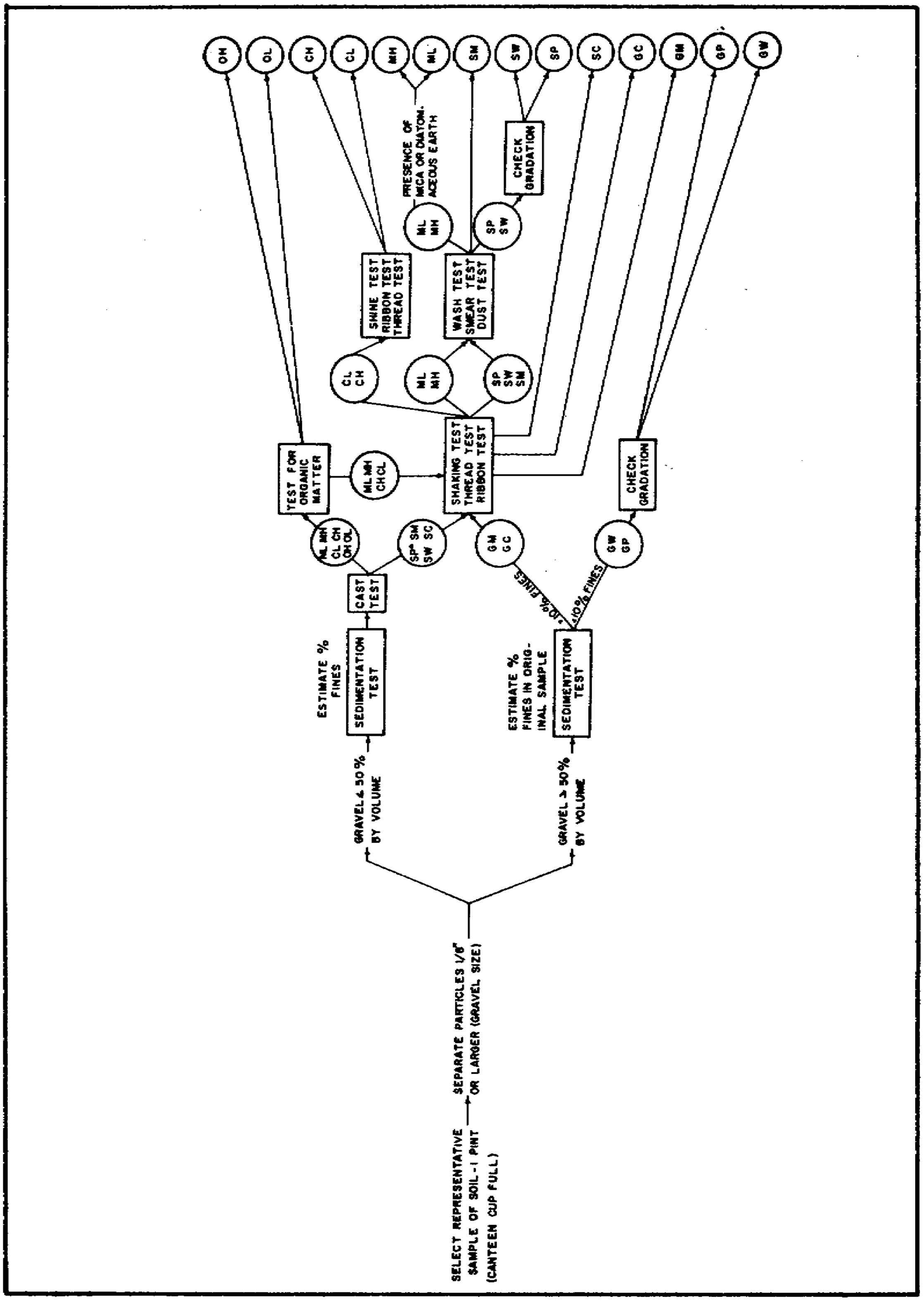
WASH, DUST, AND SMEAR TESTS

A small amount of silt (less than 5 percent), when intermixed with a coarse-grained soil, normally will not lessen the value of the soil as a construction material. However, increasing the quantity of silt will sharply reduce the strength and interfere with the free drainage characteristics of the coarse-grained soil. This makes it less desirable as a road or airfield construction material. To decide what constitutes a harmful concentration of silt by the

field identification methods generally requires extensive field experience. If the dust, wash, and smear tests are first practiced on soils of known silt contents, they can be used to produce a fairly accurate result. In the dust test, when a completely dry sample of soil (with the gravel portion removed) is dripped from a height of one or two feet onto a solid surface, a silt content higher than 10 percent will generally cause a fairly large amount of dust to be produced. In the wash test, an identical soil sample, as above, is placed in the palm of the hand, and covered with 1/8 inch of water. If the water becomes completely discolored and hides the sand grains, this indicates that the soil sample contains a silt content higher than 5 percent. In the smear test, a sample of soil, again with the gravel portion removed, is moistened to just below the sticky limit, and then smeared between the thumb and forefinger. When it produces a gritty, harsh feel, this indicates that it contains a silt content of less than 10 percent. A rough, less harsh feel, however, indicates that the sample contains more than 10 percent silt. All of the above tests can be considered as reliable indicators of the silt contents only if the engineers performing the tests are experienced.

Now look at Figure 11 on the next page. It illustrates the suggested procedure for using the tests described in the first three parts of this lesson. You will see that all the tests in the diagram can be performed in the field with no laboratory equipment.

FIGURE 22. SUGGESTED PROCEDURE FOR FIELD IDENTIFICATION



Learning Event 6
IDENTIFY THE PHYSICAL PROPERTIES OF SOIL AND THEIR EFFECTS ON ENGINEERING

The physical properties which form the basis for the Unified Soil Classification System are the percentages of gravel, sand, and fines; shape of the grain-size distribution curve; and plasticity. These same properties are the primary ones to be considered in field identification, but other characteristics observed should be included in describing the soil, whether the identification is made by field or laboratory methods.

PHYSICAL PROPERTIES

The following is a list of the properties which the military engineer would include in a soil description:

- Color
- Grain size
  - -- estimated maximum grain size
  - -- estimated percent by weight of fines (material passing the #200 sieve)
- Gradation
- Grain shape
- Plasticity
- Predominant soil type
- Secondary components of soil
- Classification symbol
- Other remarks such as-organic, chemical, or metallic content
- Compactness
- Consistency
- Cohesiveness near plastic limit
- Dry strength
- Source-residual or transported (aeolian, waterborne, glacial, deposit, etc.)

As stated before, these physical properties affect the engineering characteristics of the soil. For example, coarse-grained soils are better as a base in construction because they tend to drain better.

Table 5 illustrates the value of each soil type to construction based on its physical properties. The chart is organized into coarse-grained and fine-gained soils. Each soil type is identified by both its common name and its USCS symbol. By referring to this chart you will be able to describe any known soil's engineering characteristics.

NOTE: The compressibility and expansion of a soil is usually an undesirable construction quality (Table 5, Column 10). Thus, if a soil classified has a high to medium frost susceptible potential, then it may disqualify that soil from being used in construction. Of course, it may be of little concern in a project whether a soil expands, compresses, or has frost susceptibility. An

example of this might be a large earth berm project where it is of insignificant consequence. (Refer to Table 5, Column 9.)

We have stated before that these physical properties affect the engineering characteristics of the soil. For example, we noted that coarse-grained soils are better as a base in construction because they tend to drain better. Table 5 illustrates the value of each soil type to construction.

TABLE 5. CHARACTERISTICS PERTINENT TO ROADS AND AIRFIELDS

Major Divisions (1)	(2)	Symbol: Letter (3)	Symbol: Hatching (4)	Symbol: Color (5)	Name (6)	Value as Subgrade When Not Subject to Frost Action (7)	Value as Subbase When Not Subject to Frost Action (8)	Value as Base When Not Subject to Frost Action (9)	Potential Frost Action (10)	Compressibility and Expansion (11)	Drainage Characteristics (12)	Compaction Equipment (13)	Unit Dry Weight lb per cu ft (14)	Typical Design Values: CBR (15)	Typical Design Values: Subgrade Modulus k lb per cu in. (16)
COARSE-GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Excellent	Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	125-140	40-80	300-500
		GP		Red	Poorly graded gravels or gravel-sand mixtures, little or no fines	Good to excellent	Good	Fair to good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	110-140	30-60	300-500
		GM d		Yellow	Silty gravels, gravel-sand-silt mixtures	Good to excellent	Good	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	125-145	40-60	300-500
		GM u		Yellow		Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	115-135	20-30	200-500
		GC		Yellow	Clayey gravels, gravel-sand-clay mixtures	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	130-145	20-40	200-500
	SAND AND SANDY SOILS	SW		Red	Well-graded sands or gravelly sands, little or no fines	Good	Fair to good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	110-130	20-40	200-400
		SP		Red	Poorly graded sands or gravelly sands, little or no fines	Fair to good	Fair	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	105-135	10-40	150-400
		SM d		Yellow	Silty sands, sand-silt mixtures	Fair to good	Fair to good	Poor	Slight to high	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	120-135	15-40	150-400
		SM u		Yellow		Fair	Poor to fair	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100-130	10-20	100-300
		SC		Yellow	Clayey sands, sand-clay mixtures	Poor to fair	Poor	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100-135	5-20	100-300
FINE-GRAINED SOILS	SILTS AND CLAYS LL IS LESS THAN 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Poor to fair	Not suitable	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	90-130	15 or less	100-200
		CL		Green	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Poor to fair	Not suitable	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired roller, sheepsfoot roller	90-130	15 or less	50-150
		OL		Green	Organic silts and organic silt-clays of low plasticity	Poor	Not suitable	Not suitable	Medium to high	Medium to high	Poor	Rubber-tired roller, sheepsfoot roller	90-105	5 or less	50-100
	SILTS AND CLAYS LL IS GREATER THAN 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Not suitable	Not suitable	Medium to very high	High	Fair to poor	Sheepsfoot roller, rubber-tired roller	80-105	10 or less	50-100
		CH		Blue	Inorganic clays of high plasticity, fat clays	Poor to fair	Not suitable	Not suitable	Medium	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	90-115	15 or less	50-150
		OH		Blue	Organic clays of medium to high plasticity, organic silts	Poor to very poor	Not suitable	Not suitable	Medium	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	80-110	5 or less	25-100
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	Not suitable	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compaction not practical	-	-	-

Note:

1. Column 3, division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is on basis of Atterberg limits: suffix d (e.g., GMd) will be used when the liquid limit is 25 or less and the plasticity index is 5 or less; the suffix u will be used otherwise.
2. In column 13, the equipment listed will usually produce the required densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled. In some instances, several types of equipment are listed because variable soil characteristics within a given soil group may require different equipment. In some instances, a combination of two types may be necessary.
   a. Processed base materials and other angular materials. Steel-wheeled and rubber-tired rollers are recommended for hard, angular materials with limited fines or screenings. Rubber-tired equipment is recommended for softer materials subject to degradation.
   b. Finishing. Rubber-tired equipment is recommended for rolling during final shaping operations for most soils and processed materials.
   c. Equipment size. The following sizes of equipment are necessary to assure the high densities required for airfield construction:
      Crawler-type tractor -- total weight in excess of 30,000 lb.
      Rubber-tired equipment -- wheel load in excess of 15,000 lb, wheel loads as high as 40,000 lb may be necessary to obtain the required densities for some materials (based on contact pressure of approximately 65 to 150 psi).
      Sheepsfoot roller -- unit pressure (on 6- to 12-sq-in. foot) to be in excess of 250 psi and unit pressures as high as 650 psi may be necessary to obtain the required densities for some materials. The area of the feet should be at least 5 per cent of the total peripheral area of the drum, using the diameter measured to the faces of the feet.
3. Column 14, unit dry weights are for compacted soil at optimum moisture content for modified AASHO compaction effort.
4. In column 15, the maximum value that can be used in design of airfields is, in some cases, limited by gradation and plasticity requirements.

TABLE 5A. CHARACTERISTICS PERTINENT TO EMBANKMENTS AND FOUNDATIONS

Major Divisions (1)	(2)	Letter (3)	Symbol: Hatching (4)	Symbol: Color (5)	Name (6)	Value for Embankments (7)	Permeability Cm Per Sec (8)	Compaction Characteristics (9)	Std AASHO Max Unit Dry Weight Lb Per Cu Ft (10)	Value for Foundations (11)	Requirements for Seepage Control (12)
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Very stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired, steel-wheeled roller	125-135	Good bearing value	Positive cutoff
		GP		Red	Poorly-graded gravels or gravel-sand mixtures, little or no fines	Reasonably stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired, steel-wheeled roller	115-125	Good bearing value	Positive cutoff
		GM		Yellow	Silty gravels, gravel-sand-silt mixtures	Reasonably stable, not particularly suited to shells, but may be used for impervious cores or blankets	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	120-135	Good bearing value	Toe trench to none
		GC		Yellow	Clayey gravels, gravel-sand-clay mixtures	Fairly stable, may be used for impervious core	$k = 10^{-6}$ to 10^{-8}	Fair, rubber-tired, sheepsfoot roller	115-130	Good bearing value	None
	SAND AND SANDY SOILS	SW		Red	Well-graded sands or gravelly sands, little or no fines	Very stable, pervious sections, slope protection required	$k > 10^{-3}$	Good, tractor	110-130	Good bearing value	Upstream blanket and toe drainage or wells
		SP		Red	Poorly-graded sands or gravelly sands, little or no fines	Reasonably stable, may be used in dike section with flat slopes	$k > 10^{-3}$	Good, tractor	100-120	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SM		Yellow	Silty sands, sand-silt mixtures	Fairly stable, not particularly suited to shells, but may be used for impervious cores or dikes	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	110-125	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SC		Yellow	Clayey sands, sand-silt mixtures	Fairly stable, use for impervious core for flood control structures	$k = 10^{-6}$ to 10^{-8}	Fair, sheepsfoot roller, rubber tired	105-125	Good to poor bearing value	None
FINE GRAINED SOILS	SILTS AND CLAYS LL < 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Poor stability, may be used for embankments with proper control	$k = 10^{-3}$ to 10^{-6}	Good to poor, close control essential, rubber-tired roller, sheepsfoot roller	95-120	Very poor, susceptible to liquefaction	Toe trench to none
		CL		Green	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Stable, impervious cores and blankets	$k = 10^{-6}$ to 10^{-8}	Fair to good, sheepsfoot roller, rubber tired	95-120	Good to poor bearing	None
		OL		Green	Organic silts and organic silt-clays of low plasticity	Not suitable for embankments	$k = 10^{-4}$ to 10^{-6}	Fair to poor, sheepsfoot roller	80-100	Fair to poor bearing, may have excessive settlements	None
	SILTS AND CLAYS LL > 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction	$k = 10^{-4}$ to 10^{-6}	Poor to very poor, sheepsfoot roller	70-95	Poor bearing	None
		CH		Blue	Inorganic clays of high plasticity, fat clays	Fair stability with flat slopes, thin cores, blankets and dike sections	$k = 10^{-6}$ to 10^{-8}	Fair to poor, sheepsfoot roller	75-105	Fair to poor bearing	None
		OH		Blue	Organic clays of medium to high plasticity, organic silts	Not suitable for embankments	$k = 10^{-6}$ to 10^{-8}	Poor to very poor, sheepsfoot roller	65-100	Very poor bearing	None
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	Not used for construction		Compaction not practical		Remove from foundations	

Notes:
1. Values in columns 7 and 11 are for guidance only. Design should be based on test results.
2. In column 9, the equipment listed will usually produce the desired densities with a reasonable number of passes when moisture conditions & thickness of lift are properly controlled.
3. Column 10, unit dry weights are for compacted soil at optimum moisture content for Standard AASHO (Standard Proctor) compactive effort.

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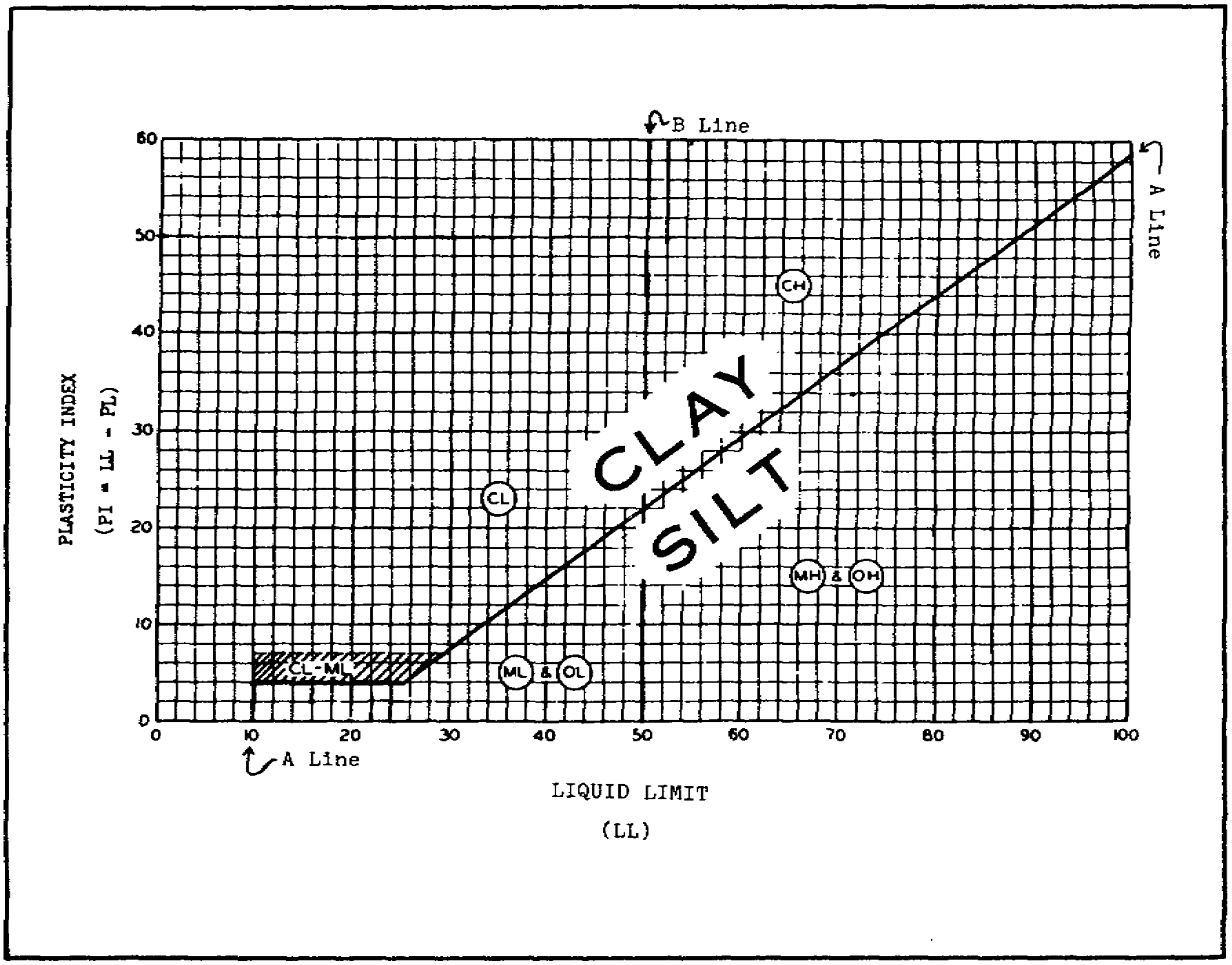
PRACTICE EXERCISE FOR LESSON 2

Instructions

Check your understanding of Lesson 2 by completing the practice exercise. There is only one correct answer to each question. Try to answer all of the questions without referring to the lesson materials.

When you have completed all of the questions, turn the page and check your answers against the correct responses. Each correct response is referenced to specific portions of the lesson material so that you can review any questions you have missed or do not understand, before continuing to the next lesson.



1. An inorganic soil has 52 percent fines, a LL of 47 percent, and a PI of 12 percent. The primary letter for this soil is __________.

2. A sieve analysis provided the following data on a soil:
   - 42 percent gravel
   - 40 percent sand.

   The primary letter for the USCS symbol is __________.

3. A coarse-grained soil with less than 5 percent fines has a primary letter of _____ or _____ and a secondary letter of _____ or _____.

4. Classify this soil sample:
   - Gravel = 48 percent
   - Sand = 50 percent
   - Smooth grain size distribution curve
   - $C_u = 5.3$
   - $C_c = 1.7$.

   The classification of the soil is __________.

Use the plasticity chart on the previous page and Figure 17 to help you classify the following soil samples:

5. Gravel = 51 percent LL = 21 percent
   Sand = 34 percent PL = 15 percent
   USCS Symbol

6. Gravel = 23 percent LL = 63 percent
   Sand = 37 percent PL = 15 percent
   USCS Symbol

7. Gravel = 26 percent $C_u = 3.8$
   Sand = 67 percent $C_c = 2.4$
   LL = 62 percent Most of the material falls between the #10 and #40 sieve.
   PI = 18 percent
   USCS Symbol

8. Black in color with a musty, leafy odor.
   LL = 37 percent
   PL = 4 percent
   USCS Symbol

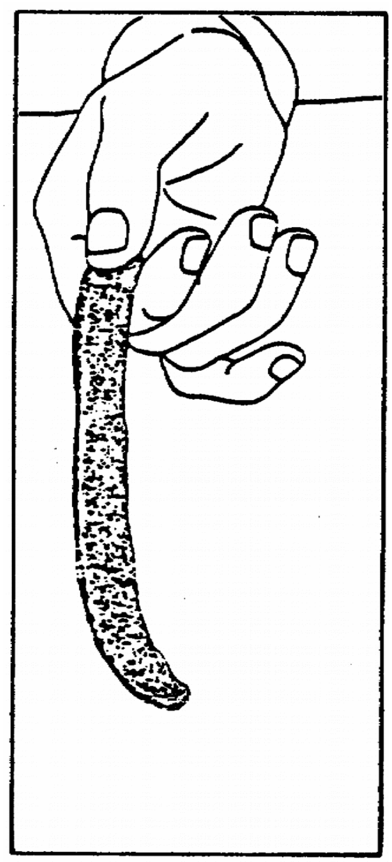
9. When performing a visual examination in the field, you will check for color, grain size, __________, grain shapes, and the undisturbed soil properties.
   a. specific gravity
   b. liquid limit
   c. grain size distribution
   d. cohesiveness

10. __________ soils can be identified by a characteristic odor when they are moist.
    a. Fine-grained
    b. Coarse-grained
    c. Organic
    d. Silty

11. When performing the dry strength test, if the sample cannot be broken with the thumb and forefingers of both hands, you deduce that the soil probably
    a. is very highly plastic
    b. contains a preponderance of clay.
    c. is highly compressible.
    d. all of the above.

12. If you rub dry __________ with a knife, you will leave a shiny spot.
    a. sand
    b. peat
    c. silt
    d. clay

13. The test in the drawing helps evaluate the ___________.
    a. plasticity
    b. grain size distribution
    c. moisture content
    d. undisturbed soil properties



14. Using Table 5, determine why ML is not suitable for airstrip construction.

___

___

___

Lesson 2/Practice Exercise Answers

ANSWER SHEET FOR PRACTICE EXERCISE

Lesson 2			**Learning Event**
1.	M (Silt).	The material is fine-grained. The Liquid Limit and the Plasticity Index plot below the A-line on the Plasticity Chart.	1
2.	G (Gravel)		1
3.	S or G/W or P		1
4.	SP	The soil is coarse grained (the percentage of fines is less than or equal to 50 percent). The predominant coarse-grained fraction is <u>sand</u>, so the primary letter is <u>S</u>. There are less than 5 percent fines, so gradation will determine the secondary letter. Because C_u is not greater than 6 (for sand), the soil is <u>poorly graded</u>, therefore the secondary letter is <u>P</u>.	2
5.	USCS Symbol: GM-GC	The soil is coarse-grained. The predominant coarse-grained fraction is gravel (51 percent). The primary letter therefore is <u>G</u>. Subtracting the PL from the LL we find that the PI is 6 percent. Plotting the LL and PI on the plasticity chart we see that the point falls within the box at the base line of the A-line, indicating that a dual classification will be used. The first and third letters are <u>G</u>, the second letter is <u>M</u>, and the fourth letter is <u>C</u>.	2
6.	USCS Symbol: SM.	The amount of fines is 40 percent which is less than 50 percent. Therefore, the soil is coarse-grained. The primary letter is <u>S</u> since sand is the predominant coarse fraction. As there are more than 12 percent fines, the type of fines will govern the selection of a secondary letter. The LL of 63 percent and the PI of 15 percent plot below the A-line on the plasticity chart indicating that the fines are silty. The secondary letter, therefore, is <u>M</u> (the symbol for silt).	2

ANSWER SHEET FOR PRACTICE EXERCISE (Cont'd)

Lesson 2			Learning Event
7.	USCS Symbol: SP-SM.		2
		Fines equal 7 percent. The soil is coarse-grained and, since sand is the predominant fraction, S is the primary letter. With 7 percent fines we know that we will have a dual classification and that we have to consider both gradation and type of fines. The soil does not meet the gradation criteria for sand, $C_u = 3.8$, which is not greater than 6. Therefore, the second letter will be a P. By plotting the LL and PI on the plasticity chart, we see that the fines are silty. Therefore, the fourth letter is M. With the first and third letters of our classification being the primary letter S, the whole symbol is SP-SM.	
8.	USCS Symbol: OL.		2
		The LL is below 50 percent so the secondary letter is L. The LL and PI plot below the A-line on the plasticity chart indicating either a silt or organic material. The description of the soil gives you the clue that the material is organic, O. The primary letter is O and the complete symbol is OL.	
9.	c.	grain size distribution.	3
10.	c.	organic.	3
11.	d.	all of the above.	4 and 5
12.	d.	clay.	4
13.	a.	plasticity.	4
14.		ML is not suitable for airstrip construction because it has very high frost potential and fair to poor drainage.	2, 4, and 6

Lesson 3
SOIL SURVEYS

TASK: Describe the Procedures Used to Direct a Deliberate Soil Survey for a Proposed Military Construction Project

CONDITIONS: Given this subcourse, a No. 2 pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by responding correctly to 75% of the examination questions.

CREDIT HOURS: 2

REFERENCE: FM 5-530

Learning Event 1
IDENTIFY TYPES OF SOIL SURVEYS

The objective of the soil survey is to obtain information relating to the physical properties of the soil and the arrangement of the underlying materials. A soil survey can determine the location, sequence, thickness, and area extent of each soil stratum, including a description and classification of the soils and their structure and stratification in the undisturbed state. Significant geologic features, such as concretions, and mineral chemical constituents also are included in the data from exploration.

The investigation is conducted in the office, in the field, and in the laboratory. It begins with a preliminary program which discloses general characteristics that will provide you with a broad understanding of soil conditions and engineering problems which may be encountered, such as drainage, slope stability, differential settlement, and equipment production rates, to name a few. The basic soils information is invaluable when planning, conducting, and interpreting later detailed soil surveys.

The end product of the soils survey is an accurate engineering analysis of the subsurface conditions which will enable you to render the safest, most economical design.

TYPES OF SOIL SURVEYS

A soil survey consists of gathering soil samples for examination, testing, and classifying soils, and developing a soil profile. Two types of soil surveys are the <u>hasty survey</u>, which is made either under expedient conditions or when time is very limited, and the <u>deliberate survey</u>, which is made when adequate equipment and time are available.

Although this lesson describes the hasty survey, it is primarily concerned with the deliberate survey.

<u>HASTY SURVEY</u>

The hasty survey should be preceded by as careful a study of all available sources of information as conditions permit. If possible, a trained person may observe soil conditions in the proposed construction area from the air. Careful <u>aerial observation</u> gives an overall picture, which is often difficult to secure at ground level because important features may be obscured in rough or wooded terrain. <u>Rapid ground observation</u> along the proposed road location or at the proposed airfield site will also yield useful information. Observation of the <u>soil profile</u> may be made along the natural banks of a stream, eroded areas, bomb craters, and other exposed places. As construction proceeds, additional soil studies will augment the basic data gained through the hasty survey and will dictate necessary modification in location, design, and construction.

Lesson 3/Learning Event 1

DELIBERATE SURVEY

The deliberate survey does not dismiss the fact that the time factor may be important; therefore, the scope of a deliberate survey may necessarily be limited in some cases. A deliberate survey is often performed while topographical data is being obtained, so that the results of the soil survey may be integrated with other pertinent information.

The principal methods of exploration used in soil surveys for roads, airfields, and borrow areas are soil samples obtained either by using hand augers or by digging a test pit. Other methods that may be used are power-driven earth augers, sounding rods, or earth moving equipment under expedient conditions to permit a hasty approach to the underlying soil.

SUBSURFACE EXPLORATION

A soil survey includes gathering data on soil layers, condition of soil in place, drainage characteristics, depth of water table, and soil profile. The explorations are conducted to determine the following information:

Location, Nature, and Classification of Soil Layers. Adequate and economic earthwork and foundation design of a structure can only be accomplished when the types and depths of soil to be encountered are known. By classifying the soils encountered, you can predict the extent of problems with drainage, frost action, settlement, stability, and similar factors. While an estimate of the soil characteristics may be obtained by field observations, you should also obtain samples of the major soil types as well as less extensive deposits, which may influence design.

Condition of Soils in Place. The moisture content and density of a soil in its natural state sometimes play an important part in design and construction. Moisture content of some soils, in place, may be so high that you should consider selecting another site for the airfield. If the natural soil is sufficiently dense or compact to meet the required specification, no further compaction of the subgrade will be required. Very compact soils in cut section may be difficult to excavate with ordinary tractor scraper units. Scarification or rooting before excavation may be necessary.

Drainage Characteristics. The drainage characteristics, in both surface and subsurface soils, are controlled by a combination of factors such as the void ratio, soil structure and stratification, temperature of soil, depth to water table, height of capillary rise, and the extent of local disturbances by roots and worms. The coarse-grained soils have better internal drainage than fine-grained soils. Remolding a soil also may change its drainage properties. Observations of the soil should be made in both the disturbed and undisturbed condition.

Ground Water and Bedrock. All structures must be constructed at such an elevation that they will not be adversely affected by the ground water table. The grade line must be raised or the ground water table must be lowered when a structure may be adversely affected by capillary rise or by the ground water table itself. Bedrock within the depth of excavation tremendously increases the time and equipment requirements for excavation. If the amount is very extensive, it may be cause for a change in the grade or even the site location.

Developing a Soils Profile. The soil profile is a graphical representation of a vertical cross-section of the soil layers from the surface of the earth downward. A description of the development of the soil profile will appear later in this lesson.

Learning Event 2
IDENTIFY THE STEPS IN A FIELD INVESTIGATION

Field investigation is done in three phases:
- Site evaluation
- Investigation of existing information
- Subsurface investigation.

SITE EVALUATION

The first step is site evaluation. The object of site evaluation is to determine the soil strata and mineral composition of rocks and to try to foresee problems which may occur in construction or future expansion.

As described above in the section on hasty surveys, the soils engineer can obtain information from areas which expose the substrata. The areas include:
- river banks
- escarpments
- highway and railroad cuts
- quarries
- existing shafts and tunnels.

EXISTING INFORMATION

The next step is to obtain existing information. There are many sources of information available to the soils engineer. Using these to the fullest extent may help shorten the investigation. These sources will be used mostly to locate small areas of a large general area which are suitable for further investigation. For the final site selection, actual field investigations must be made.

Among the sources of information to be consulted in planning a soil survey are: intelligence reports, local inhabitants, and aerial photographs.

INTELLIGENCE REPORTS AND LOCAL INHABITANTS

Intelligence Reports. Intelligence reports which include maps and studies of soil conditions usually are available for areas in which military operations have been planned. Among the best and most comprehensive of these are the National Intelligence Surveys and Engineer Intelligence Studies. These reports are a source of information on geology, topography, terrain conditions, climate and weather conditions, and sources of construction materials.

Local Inhabitants. Local inhabitants may provide information to supplement intelligence reports or provide information about areas for which intelligence reports are unavailable. Information obtained from this source would include possible location of borrow material, sand and gravel deposits, and peat or highly organic soils, and information on the climate and topography of the area.

MAPS

Maps provide valuable information, especially when planning the soil survey. In some cases, maps showing the suitability of terrain for various military purposes, prepared by friendly foreign or enemy agencies, may be of considerable value in planning. There are several kinds of maps which provide different types of information about an area under investigation.

Geological Maps. Obviously a close relationship exists between geology and soil conditions. Geological maps and brief descriptions of regions and quadrangles have been published in the folios of the U.S. Geological Survey. Generally the smallest rock unit mapped is a formation, and geological maps indicate the area extent of these formations by means of letter symbols, color, or symbolic patterns. Letter symbols on the map also indicate the location of sand and gravel pits, and the rear of the map sheet sometimes has a brief discussion entitled "Mineral Resources," describing the location of construction materials.

Topographic Maps. Ordinary topographical maps may be of some use in estimating soil conditions, particularly when used with geologic maps. Topographic maps, especially when the contour interval is 20 feet or more, tend to give only a generalized view of the land surface. Inspection of the drainage pattern and slopes can provide clues of the nature of rocks, depth of weathering, soil, and drainage. For example, sinkholes may indicate limestone or glacial topography; hills and mountains with gently rounded slopes usually indicate deeply weathered rocks; and parallel ridges are commonly related to steeply folded, bedded rock with hard rock along the ridges. Features such as levees, sand dunes, beach ridges, and alluvial fans can be recognized by their characteristic shapes and geographic location.

Agricultural Soil Maps. Agricultural soil maps and reports are available for many of the developed agricultural areas of the world. These studies are concerned primarily with surface soils, generally to a depth of about six feet. Their value as aids in the engineering study of surface soils is apparent. For example, if the same soil is shown to occur in two different areas, it can be sampled and evaluated for engineering purposes in one area, and the amount of sampling and testing can then be sharply reduced in the second area. Information on topography, drainage, vegetation, temperature, rainfall, water sources, and rock location may be found in an agricultural report. Soils usually are classified according to their texture, color, structure, chemical and physical composition, and morphology.

Aerial Photographs. The use of aerial photographs in delineating and identifying soils is based upon the recognition of typical patterns formed under similar conditions of soil profile and weathering. Principal elements which can be identified on a photograph, and which provide clues to the identification of soils to a trained observer, are landforms, slopes, drainage patterns,

erosional characteristics, soil color or "tone", vegetation, and land use. Each of the following brief descriptions serve only as an example of information which may be derived from the examination of aerial photographs.

- **Landform.** The "form" or configuration of the land in different types of deposits is definitely characteristic and can be identified on aerial photographs. For example, glacial forms such as moraines, kames, eskers, and terraces have readily identified forms. In desert areas, characteristic dune shapes indicate areas covered by sands subject to movement by wind. In areas underlain by flat-lying, soluble limestone, the aerial photo typically shows sinkholes.
- **Slope.** Prevailing ground slopes generally represent the texture of the soil. Steep slopes are characteristic of granular materials, while relatively flat and smoothly rounded slopes may indicate more plastic soils.
- **Drainage Patterns.** A very simple drainage pattern is frequently indicative of pervious soils. A highly integrated drainage pattern is frequently indicative of impervious soils, which in turn are plastic and lose strength when wet. Drainage patterns also reflect underlying rock structure. For example, alternately hard and soft layers of rock cause major streams to flow in valleys cut in the softer rock.
- **Erosional Patterns.** Considerable information may be gained from the careful study of gullies. The cross-section or shape of a gully is controlled primarily by the cohesiveness of the soil. Each abrupt change in grade, direction, or cross-section indicates a change in the soil profile or rock layers. Short, V-shaped gullies with steep gradients are typical of cohesionless soils; U-shaped gullies with steep gradients indicate deep, uniform silt deposits such as loess. Cohesive soils generally develop round, saucer-shaped gullies.
- **Soil Color.** The color of the soil is shown on the aerial photograph by shades of gray, ranging from white to black. Soft, light colors or tones generally indicate pervious, well-drained soils. Large flat areas of sand are frequently marked by uniform light gray color tones, a very flat appearance, and no natural surface drainage. Clays and organic soils frequently appear as dark gray to black areas. In general, sharp changes in the color tone represent changes in soil texture. These interpretations should be used with care.
- **Vegetation.** Vegetation may reflect surface soil types, although its significance frequently is difficult to interpret because of the effects of climate and other factors. To interpreters with local experience, both cultivated and natural vegetation may cover may be reliable indicators of soil type.
- **Land Use.** Ready identification of soils is frequently facilitated by observing agricultural land use. For example, orchards require well-drained soils, and the presence of an orchard on level ground would imply a sandy soil. Wheat is frequently grown on loess-type soils. Rice usually is found in poorly draining soils underlain by impervious soils, such as clay. Tea grows in well draining soils.

SUBSURFACE INVESTIGATION

The third phase of the field investigation is to obtain data on the subsurface soils and formations. You may do this directly with Samples or indirectly with geophysical surveys and seismic probes. Table 6 shows the range of possible methods of subsurface exploration.

TABLE 6. METHODS OF SUBSURFACE EXPLORATION

GROUP	TYPE	METHOD		MEASUREMENTS OR METHODS OF ADVANCE	INDICATION OF CHANGE IN MATERIAL	TYPE FOR FORMATION	USE IN CIVIL ENGINEERING
INDIRECT METHODS	Geophysical Methods (1)	Gravitational	Gravimeter Pond	Intensity of gravitational field	Anomalies in grav. field No depth control	Rock ridges, domes, intrusions, faults, steeply inclined strata	Not used in Civil Engineering
			Torsion Balance	Curvature of gravitational field			
		Magnetic Methods		Intensity of magnetic field supplemented by *inclination, declination*	Anomalies in magnetic field *Limited depth control*	Ore bodies, faults, ridges, and intrusions of ig. mag. rocks	Recon. rock ridges, faults; rapid & econ.; application limited.
		Electrical (Galvanic)	Resistivity	Current and potential (voltage) drop	Variations in resistivity	Rock, soils, and ground water; horizontal and inclined strata at shallow to medium depths	Recon. gen. strat.; detect. of irreg. Rapid, fairly reliable with correl. borings, including repre. samples
			Pot. drop ratio	Ratio pot. drop between 3 points	Variations in pot. drop ratio		
		Seismic	Refraction	Travel times of refracted waves	*Velocity of comp. waves*		
			Reflection	Travel times of reflected waves	Velocity of comp. waves	Deposits at depths over 2000 ft	Not used in Civil Engineering
		Continuous Vibration		Contin. waves, variable frequency phase, amplitude, power, settlement	Variat. velocity, amplitude etc. of shear waves	Soil and rock, shallow depths, horizontal and inclined strata	Recon. general stratigraphy, dynamic properties; in development
	Probing or Sounding	Rod Alone	Simple Point	Driving by drop hammer	Blows: penetration	All soils without large stones	Recon. rock and rough soil profiles, rapid, not always reliable.
			Screw Point	Static pressure and rotation	Rev's: penetration	Med. to hard cohesive soils	
			Cone or Disk	Static pressure, *constant speed*	*Force:* penetration	Soft to stiff and dense soils	Shallow recon. and control tests
		Rod with a Sleeve Pipe	Wash. Point	Alternating jetting and jacking	Variations in point resistance alone	Primarily cohesionless soils	Compactness profiles, sand, silt
			Lge Cone Point	Alternating jacking and driving rod and sleeve pipe. *In some cases* concurrent jacking of rod & sleeve.		Soft to hard and dense soils without stones & boulders	Reconnaissance, detection irregularities, detail stratigraphy but without positive identification; correlate with borings. Fast, inexpensive, indication of compactness, strength, bearing capacity
			Flush Cone Point		Variat. in point resistance and skin friction		
			Cone and Collar				
		Kjellman "in situ" Method		Insertion & withdrawal of resistor	Withdrawal resistance	Primarily soft and loose soils	
SEMI-DIRECT METHODS	Borings	Displacement Boring	Silt Cup Sampler	Driving closed sampler into the soil, rotation, release of piston, sampling	Blows or static forces versus penetration	Loose to medium cohesionless soils; soft to stiff cohesive soils	Recon. and detailed exploration Rapid under favorable conditions.
			Piston Samplers				
		Wash Boring (3)		Light chopping, strong jetting; removal of cuttings by circulating water	Cuttings in water. rate of progress (2)	Soft to stiff cohesive and fine coarse cohensionless soils	Recon. to special explorations, ground water; inexpensive equip.
		Percussion Drilling — also called Cable-Tool Drilling		Power chopping; periodic removal of slurry with bailers or sandpumps	Cuttings in slurry. rate of progress.(2)	Soil and rock but difficult in soft sticky clay or loose sand	Penetrat. gravel, boulders, rock; supplementing wash, auger borings
		Rotary Drilling		Power rotation of bit; cuttings removed by circulating drilling fluid	Cuttings in fluid, rate of progress (2)	Soil and rock, except stony or very porous soil, fissured rock	Detailed and special exploration; fast; water observations difficult
		Auger Boring		Hand or power operat. with periodic withdrawal or use of contin. auger	Soil removed constitutes representative sample	Medium to stiff cohesive soils Part. saturated sand and silt	Shallow recon. or detail explor. Power operat., fast; special expl.
DIRECT METHODS		Continuous Sampling		Alternating sampling and cleaning with drive samplers or core barrels	Samples obtained are represent. or undisturb.	All soils and rock—cohesionless soils *may require freezing*	Best method for detailed soil expl *Majority of explorations in rock*
	Accessible Explorations	Test Pits and Trenches Caissons, Drifts, Tunnels		Excavation by hand and power tools, Use of explosives, sheathing of walls	Inspection, mapping sampling, and testing material in situ	Soil and rock; unstable soils require ground water control, compressed air, or freezing	Detailed and special exploration. Expensive but best of all methods except when load reduction causes soil displacement and disturbances
		Accessible Borings		Power operated disk or bucket augers; single tube core barrels; mucking			

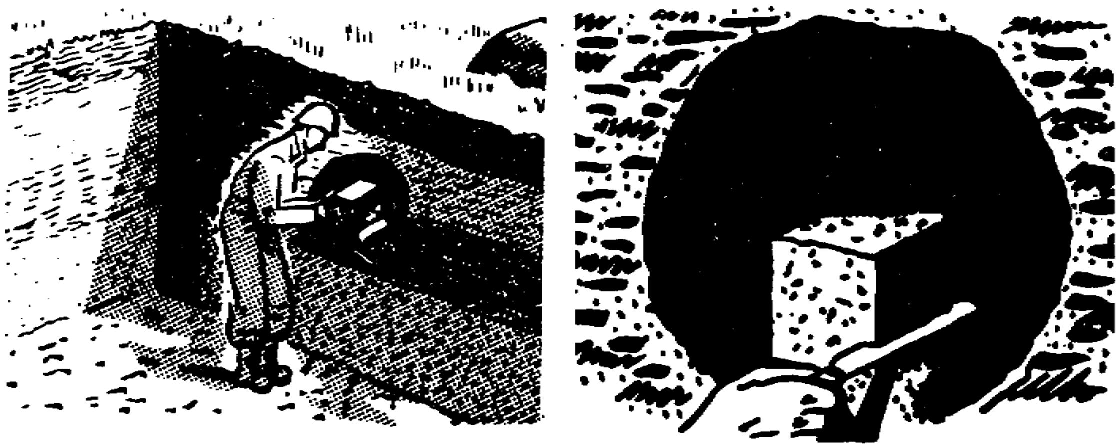
(1) Only principal methods listed. (2) Samples of cuttings, settled from wash water, slurry, or drilling fluid, are called "Wet Samples". They are non-representative for positive identification of soil strata; however, the borings make separate sampling operations possible. (3) Wash borings with representative samples taken each stratum often called "Dry Sample Borings".

Sampling Methods

The following paragraphs describe the conventional methods of subsurface sampling.

Test Pits. A test pit is an open excavation which is large enough for a man to enter and study the soil in its undisturbed condition. This method provides the most satisfactory results <u>for observing the natural condition of the soil and collecting undisturbed samples</u>. The test pit usually is dug by hand but power excavation by dragline, clamshell, bulldozer, backhoe, or a power-driven earth auger can expedite the digging. Load bearing tests can also be performed on the soil in the bottom of the pit. Figures 23 shows a soldier taking a chunk sample in a test pit.

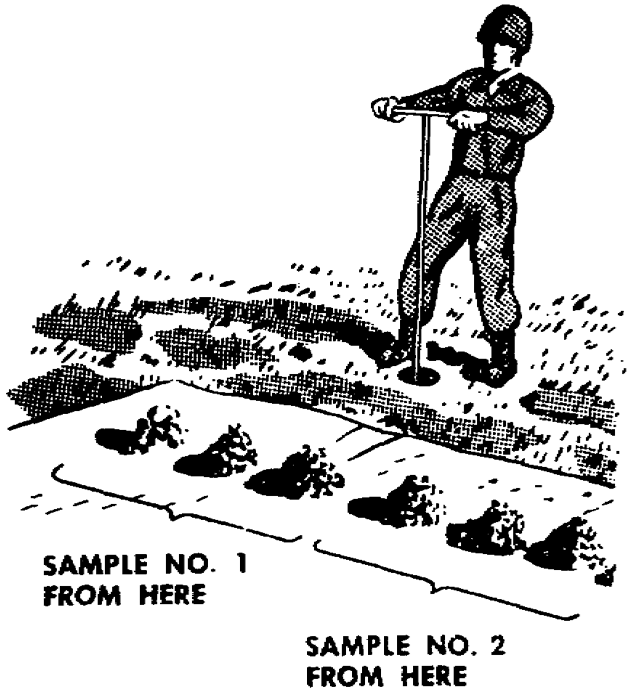
FIGURE 23. TAKING A CHUNK SAMPLE FROM A VERTICAL FACE



Test Holes. Test hole exploration includes several methods as described below.

Hand Auger. The use of the hand auger is the most common method of digging test holes. It is best suited to cohesive soils but can be used on cohesionless soils above the water table, provided the diameter of the individual aggregate particles is smaller than the bit clearance of the auger. The auger borings are principally used for work at shallow depths. By adding pipe extensions, the earth auger may be used to a depth of about 30 feet in relatively soft soils. The sample is completely disturbed and is satisfactory for determining the soil profile, classification, moisture content, compaction capabilities, and similar properties of the soil. Figure 24 shows a soldier obtaining samples with a hand auger.

FIGURE 24. OBTAINING INDIVIDUAL BAG SAMPLES FROM AN AUGER BORING



Methods of Subsurface Exploration and Sampling. Table 7 shows methods of underground exploration and sampling in a condensed table.

TABLE 7. METHODS OF UNDERGROUND EXPLORATION AND SAMPLING

Common name of method	Materials in which used	Method of advancing the hole	Method of sampling	Value for foundation purposes
Auger boring	Cohesive soils and cohesionless soils above ground water elevation.	Augers rotated until filled with soil and then removed to surface.	Samples recovered from material brought up on augers.	Satisfactory for highway exploration at shallow depths.
Well drilling	All soils, rock, and boulders.	Churn drilling with power machine.	Bailed sample of churned material or clay socket.	Clay socket samples are dry samples. Bailed samples are valueless.
Rotary drilling	All soils, rock, and boulders.	Rotating bits operating in a heavy circulating liquid.	Samples recovered from circulating liquid.	Samples are of no value.
Test pits	All soils. Lowering of ground water may be necessary.	Hand digging or power excavation.	Samples taken by hand from original position in ground.	Materials can be inspected in natural condition and place.

PLANNING THE SOIL SURVEY

Lesson 3/Learning Event 2

PLANNING THE SOIL SURVEY

The location of auger holes or test pits will depend upon the particular situation. In any case, the method described locates the minimum amount of holes. The completeness of the exploration will depend on the time available. A procedure for road, airfield, and borrow area investigation will be described.

Subgrade and Borrow Areas

Subgrade. Since soil tests should be made on samples representing the major soil types in the area, the first step in subgrade exploration is to <u>develop a general picture of the subgrade conditions</u> to assist in determining the representative soils. Perform a field reconnaissance to study landforms and soil conditions in ditches and cuts. Techniques have been developed whereby aerial photographs can be used for delineating areas of similar soil conditions. Full use should be made of existing data in agricultural soil maps for learning subsurface conditions.

The second step usually consists of <u>preliminary borings spaced at strategic points</u>. Arbitrary spacing of these borings at regular intervals is not recommended because it does not give a true picture. Intelligence use of the procedure described above, especially the technique of identifying soil boundaries from aerial photographs, will permit strategic spacing of the preliminary borings to obtain the maximum possible information with the least number of borings. In theater of operations cut areas, all holes should extend four feet below final subgrade elevation, if possible. In theater of operations fill areas, they should extend four feet below the natural ground elevation. The boring requirements stated above usually will result in the borings penetrating beyond the depth of maximum frost penetration (or thaw in permafrost areas). Where the above requirements do not achieve this result, the borings must extend to the depth of maximum frost (or thaw) areas.

Step three is to obtain soil samples for <u>classification purposes</u> in these preliminary borings. After these samples are classified, soil profiles should be developed, and representative soils should be selected for detailed testing. Test pits, or large-diameter borings, should then be made to obtain the samples needed for testing, or in-place pit tests. The types and number of samples required will depend on the characteristics of the subgrade soils. Subsoil investigations in the areas of proposed pavement must include measurements of the in-place water content, density, and strength. These are used to determine the depth of compaction and to ascertain the presence of any soft layers in the subsoil.

Borrow Areas. When material is to be borrowed from adjacent areas, borings should be made in these areas and carried two to four feet below the anticipated depth of borrow. Samples from the borings should also be classified and tested for water content, density, and strength.

Select Material and Subbase

Areas within the airfield site and within a reasonable haul from the site should be explored for possible sources of select material and subbase. Exploration procedures are similar to those described for subgrades since the select material and subbase generally are natural materials. Test pits or large auger borings put down with power augers are needed in gravelly materials.

Base and Pavement Aggregates.

Since these materials are generally crushed and processed, you should make a survey of existing producers plus other possible sources in the general area. Significant savings have been made by developing possible alternate quarry sites near the airfield location. This is particularly important in remote areas where no commercial producers are operating and in areas where commercial production is limited in quantity.

LOCATING, NUMBERING, AND RECORDING SAMPLES

The engineer in charge of the soil survey is responsible for properly surveying, numbering, and recording each auger boring, test pit, or other exploration investigation. A log is kept of each test hole which shows the elevation (or depth below the surface) of the top and bottom of each soil layer, the field identification of each soil encountered, and the number and type of each sample taken. Other information which should be included in the log is that relating to density of the soil, changes in moisture content, depth to ground water, and depth to rock. A typical boring log from a deliberate survey is shown in Figure 25. The next page shows what to include on that log.

FIGURE 25. SAMPLE BORING LOG

REPORT OF FOUNDATION AND BORROW INVESTIGATION

Date
5 Aug 1986

Site	Type of Exploration	Boring Number	Location	Ground Elevation
Airfield Jamock	Hasty	1	Sta 0+00	236'

Purpose of Exploration

Determine Soil Profile along Runway Centerline

Depth Below Surface	Elevation	Sample Number	Graphic Log	Group Symbol	Description, Test Data, and Remarks
1" = 2'	235'	No 1 at 1/2'		OH	Dark Brown and very plastic. Typical Top Soil of the Area
1'	233'	No 2 at 2 1/2'		SM	Soil with low cohesion, some sand with large percentage of silt.
3'	231			SC	Coarse Sandy Soil with a plastic binder material Light red color
5'	229'	No 3 at 7'		CH	Brown Sticky clay, very high plastic qualities Ribboned out to 4 1/2 inches with little trouble Rolled into a thread very readily
7'					

Depth to Water Table	Submitted By
3 feet	SP4 McGurk

WHAT TO INCLUDE ON A BORING LOG

1. Depth below ground surface.
2. Elevation of soil layers and ground water table.
3. Thickness of layers.
4. Graphical symbol of the soil type.
5. Description of soil.
6. Position where soil sample is taken; whether disturbed or undisturbed.
7. Sample number.
8. Natural moisture content, in percent of dry weight of soil.
9. Number of blows of a 140-pound or 300-pound hammer falling 30 inches to penetrate a 2-inch diameter sampling device or a casing one foot into soil.
10. Notes indicating position of ground water table, encountered tree roots, or other pertinent facts.
11. Title of the project, job and/or contract number.
12. Location of the project.
13. Boring number.
14. Surface elevation of the boring.
15. Date.
16. Name of the foreman in charge of drilling.

The type of tools used in making the boring should be recorded. If the tools were changed, the depth at which the change was made and the reason for change should be noted. Incomplete or abandoned borings should be described with no less care than successfully completed drill holes. The notes should contain everything of significance observed on the job, such as the elevations at which wash water was lost from the hole.

The information contained in the field notes should be assembled in the form of boring logs in which the boundaries between the strata are plotted at their correct elevation on a suitable vertical scale.

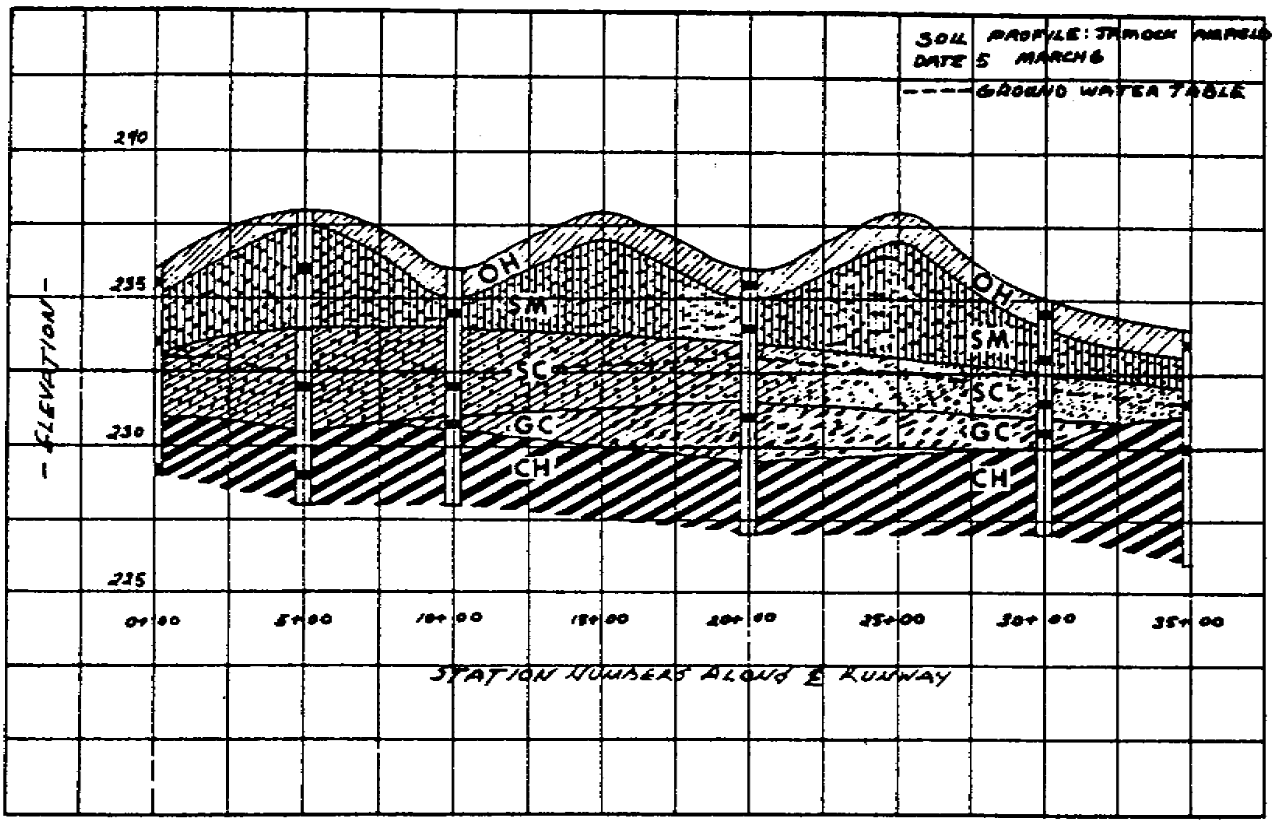
THE SOIL PROFILE

Development

The engineer keeps detailed field logs of all auger borings or test pits made during the soil survey. When the survey has been completed, the information contained in the separate logs is consolidated. In addition to the classification and depth of soil layers encountered in each log, it is desirable to show the natural water contents of fine-grained soils along the side of each log when possible as shown in Figure 25. Also the elevation of the ground water table should be noted. The elevation is determined during the soil survey by observing the level at which free water stands in the test holes. To get an accurate determination, holes should be covered and inspected 24 hours after being dug, in order to allow the water to reach maximum level. The soil profile shown in Figure 26 is a graphical representation of a vertical cross-section of the soil layers from the surface of the earth downward. It shows the location

of test holes, profile of the natural ground to scale, location of any ledge rock encountered, field identification of each soil type, thickness of each soil stratum, and profile of the water table.

FIGURE 26. TYPICAL SOIL PROFILE



Uses of the Soil Profile

The soil profile has many practical uses in the location; design, and construction of roads, airfields, and structures. It has a great influence in the location of the grade line, which should be placed so that full advantage is taken of the best soils which are available at the site. The profile will show whether soils to be excavated are suitable for use in embankments, or if borrow soils will be required. It may show the existence of undesirable conditions, such as peat or organic matter or bedrock close to the surface, which will require special construction measures. It will aid in the planning of drainage facilities so that advantage may be taken of the presence of well-draining soils. It may indicate that special drainage installations will be needed with soils which are more difficult to drain, particularly in areas where the water table is high. Considerations relative to capillary and frost action may be particularly important when frost-susceptible soils are shown on the profile.

RECOMMENDED PROCEDURES FOR SOIL SURVEYS

The following guide and step-by-step procedures are a summary and review of soils exploration.

Objective of Soil Exploration

Soil Types and Securing of Samples.
Condition of Soil In-place.
- Density
- Moisture content.

Drainage Characteristics.
Depth to Ground Water and Bedrock
Development of a Soil Profile for the Area.

Sources of Information

Published Information.
- Geological and topographical reports, and maps.
- Agricultural soil bulletins and maps-require careful interpretation and knowledge of local terms.
- Aerial photographs-used to predict subsurface conditions.
- Previous explorations for nearby construction projects.

Field Information

General observation of road cuts, stream banks, eroded slopes, earth cellars, mine shafts, existing pits and quarries, etc.
- Test holes made with hand auger or power auger if necessary and available.
- Test pits, necessary where hand auger cannot penetrate, or large samples are required.
- Local inhabitants-preferably trained observers such as contractors, engineers, quarrymen, etc.

Planning of General Layout

Primary Objective. The primary objective is to determine the extent of the various soil types, vertically and laterally, within the zone where earthwork may occur.

Airfields Exploration. Place borings at high and low spots, wherever a soil change is expected, and in transitions from cut to fill. There is no maximum or minimum spacing requirement between holes; however, the number of holes must be sufficient to give a complete and continuous picture of the soil layers throughout the area of interest. As a general rule, the number of exploration borings required on a flat terrain with uniform soil condition will be less than in a terrain where the soil conditions change rather frequently.

Exploration borings generally should be conducted at the point of interest, and located in a manner to get the maximum value from each boring. This may require exploration borings in the centerline as well as edges of runways or roads, but no specific pattern should be employed except perhaps a staggered or offset pattern, to permit the greatest coverage.

It is generally accepted policy to conduct the exploration borings at the edges of existing pavements, unless these pavements have failed completely, in which case the reason for the failure should be found.

Large cuts and fills are the most important areas for detailed exploration.

Depth of Exploration in the Theater of Operations. The cut section should be four feet below subgrade, if possible. (The fill section should be four feet below original ground level, if possible.) Effort should be made to locate the ground water table.

Procedures in Sampling

Exploration holes or pits must be carefully logged. Samples must be accurately located and numbered. The elevation and exact location of each hole should be determined and tied into the site layout.

Preparation of Soil Profile

The soils profile shows boundaries of soil strata, location and depth of test holes and samples, elevation of bedrock, and water table. Laboratory test results should be included when available. The soils profile is used to locate grade line, for excavation and grading plan, and for drainage plan.

Learning Event 3
PREPARE A TECHNICAL SOIL REPORT

The organization and presentation of the soils report is very important. It must be well organized and presented in a logical and concise format with emphasis on the technical conclusions. The following outline should help to organize a technical soils report successfully:

1. PROJECT
   - 1--01 General Description of Project
   - 1--02 Extent and Authority for Proposed Construction
   - 1--03 Purpose and Scope of Report

2. DESCRIPTION OF SITE
   - 2--01 Description of Location and Existing Facilities
   - 2--02 Topography, Cultivation, and Drainage

3. GEOLOGY
   - 3--01 Description of Subsurface Materials At and Near Site
   - 3--02 Description of Overburden and Rock

4. AGGREGATES
   - 4--01 Field Explorations
   - 4--02 Field Tests
   - 4--03 Laboratory Tests
   - 4--04 Results of Field and Laboratory Investigations

5. FOUNDATION CONDITIONS
   - 5--01 Field Explorations
   - 5--02 Field Tests
   - 5--03 Laboratory Tests
   - 5--04 Results of Field and Laboratory Investigations

6. FILLS AND BORROW MATERIALS
   - 6--01 Field Explorations
   - 6--02 Field Tests
   - 6--03 Laboratory Tests
   - 6--04 Results of Field and Laboratory Investigations

7. CONCLUSIONS AND RECOMMENDATIONS
   - 7--01 Site Selection
   - 7--02 Economical Design
   - 7--03 Minimum Specifications

ANNEXES

A. General Plan Drawings
B. Location Plan Drawings (existing and proposed features)
C. Profiles
D. Cross-Sections
E. Boring Logs
F. Laboratory Testing Data
G. Field Testing Data

It can be seen from an inspection of the outline that not every subject will apply to every report and that some of the items must be repeated several times in the same report. For example, items 5, 6, and 7 would have to be repeated for each runway in an airfield and item 4--03 might be omitted for expedient situations.

Frequently, portions of the information shown in the outline will be required at different time intervals. For this reason, a preliminary report and several supplementary reports may actually be made before the project is completed. However, if all of the information provided follows the same basic outline, filing the data and assembling the final report will be greatly simplified.

The type of survey conducted will determine the length and detail of the report. In the hasty survey, most of the items can be covered in one or two sentences and almost all of the annexes can be omitted. When a deliberate survey is made, it may be necessary to make a detailed soil profile and detailed plan drawing might be required.

PRACTICE EXERCISE FOR LESSON 3

Instructions

Check your understanding of Lesson 3 by completing the practice exercise. There is only one correct answer to each question. Try to answer all of the questions without referring to the lesson materials.

When you have completed all of the questions, turn the page and check your answers against the correct responses. Each correct response is referenced to specific portions of the lesson material so that you can review any questions you have missed or do not understand, before continuing to the next lesson.

1. When performing a deliberate soils survey, there are three phases: an on- site evaluation, a study of existing information, and a
   a. study of the vegetation.
   b. subsurface investigation.
   c. taking of some disturbed samples.
   d. a gathering of local intelligence.

2. Aerial photographs are an excellent source of information when making a site selection. List three of the types of information which aid in soils identification.
   a. __________.
   b. __________.
   c. __________.

3. The most common method of manually digging test holes is to use the
   a. CBR mold
   b. pick and shovel
   c. hand auger
   d. spoon

4. What is a soil profile?

____

____

____

5. Soils engineers obtain information from <u>areas</u> which expose the substrata. List three <u>areas</u> where the substrata is exposed.
   a. __________.
   b. __________.
   c. __________.

6. Which of the following elements would be found in an agricultural report?
   a. Geological and topographical information, terrain conditions, and sources of construction materials.
   b. Location of borrow material, sand and gravel deposits, and information on the climate and topography of an area.
   c. Information on topography, drainage, vegetation, temperature, rainfall, water resources, and rock locations.
   d. Map letter symbols, colors, and symbolic patterns.

7. A technical soils report will contain Annexes and
   a. 9 major headings.
   b. 7 major headings.
   c. 5 major headings.
   d. 3 major headings.

ANSWER SHEET FOR PRACTICE EXERCISE

Lesson 3		**Learning Event**
1.	b. subsurface investigation.	2
2.	Any three of the following: landforms soil color slope vegetation erosional pattern drainage pattern land use	2
3.	c. hand auger	1
4.	A soil profile is a drawing of a cross-section of the soil layer compiled from data in field logs.	
5.	Any three of the following: river bank escarpments highway and railroad cuts quarries existing shafts and tunnels	2
6.	c.	2
7.	b.	3

Lesson 4
FIELD CONTROL PROCEDURES

TASK: Describe the Procedures Used to Determine Field Density and Moisture Content After Soil Emplacement and Direct Corrective Actions

CONDITIONS: Given this subcourse, a No. 2 pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by responding correctly to 75% of the examination questions.

CREDIT HOURS: 2

REFERENCE: FM 5-530

Learning Event 1
DETERMINE FIELD MOISTURE CONTENT

Proper field control is of paramount importance in earthwork construction. The control tests are conducted on the soil at the job site as construction proceeds. If at any time the tests indicate that operations are not producing a soil condition specified by the design tests, immediate action should be taken to remedy the situation.

REQUIRED RELATIONSHIPS AND CALCULATIONS

When determining field moisture content, you will need to refer to the relationships and equations noted below:

- $\text{Density} = \dfrac{\text{weight}}{\text{volume}}$
- $\text{Wet Density or Wet Unit Weight} = \dfrac{\text{weight of wet sample}}{\text{volume of wet sample}} = \text{lbs/cu ft}$
- $\text{Moisture Content in Percent} = \dfrac{\text{weight of water in sample}}{\text{weight of dry soil}} \times 100$
- $\text{Dry Density} = \dfrac{\text{wet unit weight}}{1 + \left(\dfrac{\text{moisture content}}{100}\right)} = \dfrac{\text{wet density}}{1 + \left(\dfrac{w}{100}\right)} = \text{lbs/cu ft}$

FIELD MOISTURE CONTENT DETERMINATION

The specified density is expressed in terms of dry unit weight. Therefore, the moisture content must be calculated in conjunction with the wet unit weight (wet density) in order to determine whether you must add or remove moisture from the in-place soil to achieve the optimum moisture content. This is a necessary field procedure in the construction of embankments and compaction of highway subgrades. Adjustment of moisture during construction can be done only if the moisture content is known promptly. Often you cannot afford the time required for oven drying.

Experienced engineers can judge moisture content by field examination. The best and most accurate method uses an oven with temperature control. If time is not a consideration, the soil may be air-dried in the sun. Under expedient conditions, the soil sample may be dried in a frying pan or container heated by an external source. Because organic material may be burned off by high temperatures an error may result.

Another expedient method is to saturate the soil sample in alcohol and to burn the alcohol off. However, this procedure must be done carefully and repeated several times to achieve the best results. Also, the speedy moisture tester, a component of the soil test set, can be used. The speedy moisture test is the preferred method for field determination. It is the test most often used in the field.

TEST PROCEDURE FOR THE OVEN OR ALCOHOL METHOD

- Record identifying information of the sample on a data sheet (DD Form 1205).
- Weigh and record the weights of the containers to be used in the test.
- Place the sample in a container, weigh it, and record the total weight of the container (tare) and wet soil. If the weight of the sample is less than 100 grams, weigh it to the nearest 0.1 grams, otherwise the weight should be to the nearest 1.0 gram.
- Place the open container and sample in an oven heated to 110° ±5°C and dry until the sample weight becomes constant. This will require 8 to 12 hours.
- Remove the container from the oven and place it in the desiccator to cool. If the container is too large for the desiccator, allow the sample to cool to room temperature in the open air.
- After the sample has cooled, weigh it and the container and record the weight (tare and dry soil) on the data sheet.
- Calculations. The moisture content (in percent) is equal to:

$$W = \frac{\text{weight of water}}{\text{weight of dry soil}} \times 100$$

$$= \frac{\text{weight of wet soil} - \text{weight of dry soil}}{\text{weight of dry soil}} \times 100$$

$$= \frac{W_w}{W_s} \times 100$$

EXAMPLE:

A pan weighing 44 grams was used to contain a sample of soil for determination of its moisture content. The total weight, including the pan, was 189.39

and after drying was reduced to 170.0 grams. What is the resulting percent moisture in the soil?

- Weight of water = (weight of wet sample plus tare) – (weight of dry sample plus tare) = 189.3 – 170.0 = 19.3 grams

- Weight of dry soil = (weight of dry sample plus tare) – (weight of tare) = 170.0 – 44.0 = 126.0 grams

- Water content = $100 \times \frac{\text{weight of water}}{\text{weight of dry soil}} = 100 \times \frac{W_w}{W_s}$

$$W = 100 \times \frac{19.3}{126.0} = 15.3 \text{ percent}$$

TEST PROCEDURE FOR THE SPEEDY MOISTURE TESTER

The test procedure for the 26 gram speedy moisture tester using CaC_3 (calcium carbide) is as follows:

- Weigh a 26 gram sample of soil.
- Place the soil sample and two 1-1/4 inch steel balls in the large chamber.
- Place three scoops of reagent in the cap. Then with the pressure vessel in a horizontal position, insert the cap into the pressure vessel, and tighten the clamp to seal the cap to the unit.
- Raise the moisture tester to a vertical position so that the reagent falls into the vessel.
- Holding the moisture tester horizontally, manually rotate the device for 10 seconds so that the steel balls are put into orbit around the inside circumference, and then rest for 20 seconds. Repeat the shake-rest cycle for a total of 3 minutes. Do not allow the steel balls to fall against either the cap or orifice leading to the dial, since this might cause damage.
- Read the pressure gage of the moisture tester and determine the moisture content of the soil on a dry-weight basis from the conversion chart. Record the moisture content.
- When the sample is dumped, examine it for lumps. If the soil sample is not completely broken down, increase the time limit (shaking unit) by one minute on the next test.

Learning Event 2
IDENTIFY METHODS AND APPARATUS FOR THE UNDISTURBED SAMPLE METHOD

Tests on undisturbed samples are used when the base design calls for compacted soil, such as highly compressible clay which loses strength upon remolding, or when correlating field in-place tests to the design moisture condition.

Field control consists of taking samples for moisture content and density determinations as construction proceeds. Densities obtained are compared with minimum densities established for the particular job. Water contents are compared, generally, with the optimum moisture content previously established to see that compaction is taking place within the desired range or to permit its adjustment, if necessary.

The preferred undisturbed field sample for checking density is the undisturbed sample of known dimensions.

Lesson 3 of this subcourse covers soil samples in detail. In this lesson we will survey the three methods of undisturbed sampling regular chunk, irregular chunk, and drive sampler. While newer methods are being developed, these methods are still used in the field.

REGULAR CHUNK METHOD

As a military engineer you may direct your personnel to obtain a regular chunk sample. He or she will remove a regularly shaped sample from an excavation in the subgrade (or test pit). The chunk is sealed with three coats of melted paraffin. Then it is wrapped in cheese cloth, sealed in paraffin again, and shipped to the laboratory in a specially constructed container. However, it may also be tested on site for expediency.

IRREGULAR CHUNK METHOD

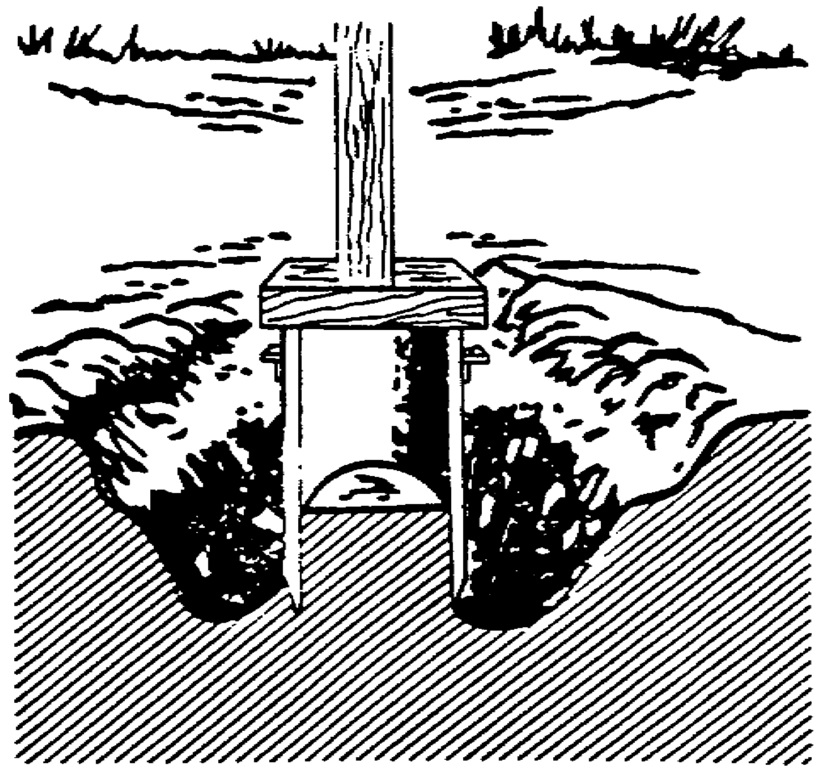
The regularly shaped sample is preferable, but sometimes large stones in the soil will prevent you from obtaining one. In this case you will obtain an irregular chunk. This sample must also be sealed in paraffin and carefully shipped to the laboratory. To determine the volume you will use water displacement. Logically, the chunk sample methods do not work on cohesionless soils.

DRIVE SAMPLER METHOD

The drive sampler method is not truly an undisturbed sample method. Some compression may occur particularly if a California Bearing Ratio mold (with a thicker cylinder) has been used. When taking a cylinder sample, first measure and weigh the cylinder, then drive the cylinder into the soil using a hand-held hammer. The sample is immediately sealed in the tube with paraffin.

You can obtain undisturbed samples from a greater depth in test holes with a thin-walled tube with a sharpened cutting edge.

FIGURE 27. SAMPLE WITH CBR COMPACTION MOLD



Learning Event 3
IDENTIFY METHODS AND APPARATUS FOR THE DISTURBED SAMPLE METHOD

If the soil is not in proper condition during construction to remove an undisturbed sample, the density determination requires measuring the volume of the hole after the sample is removed. The procedure consists of filling the hole with a measured quantity of a known-density material, such as sand, oil, or water, and computing the volume of the hole which is equal to the volume of soil removed. The soil's moisture content and density are then determined. This method is called the disturbed sample method.

The method you choose depends on the type of soil and the equipment available. On moist, cohesive, fine-grained soils, undisturbed samples using the samplers may be sufficient. Coarse-grained soils or cohesionless oils make it difficult, obtain an undisturbed sample. In these soils, density determination by the <u>displacement method</u> may be required. <u>Sand-displacement</u> may be used on any type of base course or subgrade material. <u>Oil-displacement</u> cannot be used on highly pervious soils, or crushed stone or slag base courses. In addition, if the pavement to be used is asphaltic concrete, the residual oil and spillage will tend to soften the asphalt. <u>Water-displacement</u> requires the use of a balloon to contain the water and can be used on any type of soil.

SAND DISPLACEMENT

The sand-displacement method may be used in either fine- or coarse-grained materials. This method is so named because a calibrated sand is used to determine the volume of the hole from which the sample has been taken.

Requirements

The test consists of digging out a sample of the material to be tested, determining the volume of the hole, and determining the dry weight of the sample. There are three requirements that must be met for this test:

- The volume of the sample must be 0.05 cubic foot or larger.
- A double-cone cylinder must be used. This permits calibrating the sand each day the tests are performed.
- The sand must be clean, dry and free-flowing with a constant moisture content while performing the test. Uniformly-graded and well-rounded sand passing a #20 sieve and retained on a #40 sieve is most suitable for this test. There should be practically no material finer than the #200 sieve in the sand.

Calibration

The volume of the jar and connecting cone up through the valve, and the empty weight of the apparatus must be known before the sand can be calibrated. One other calibration must be made to account for surface irregularities between the surface of the cone base and the surface to be tested.

Apparatus Calibration. To determine the weight and volume of the apparatus, follow these procedures:

- Weigh the empty dry cone and jar, and record the weight (in grams).
- Screw the cone lightly on the jar, place the apparatus upright and open the valve.
- Fill the apparatus with water at room temperature until the water level stands some distance up in the top cone. Make sure no air bubbles are trapped in the apparatus.
- Close the cone valve, pour off the excess water, shake the apparatus to check for entrapped bubbles, and dry the cone and outside of the apparatus.
- Weigh the water-filled apparatus and record the weight (in grams).

Figure 28 shows the apparatus used in the sand displacement method.

FIGURE 28. SAND DISPLACEMENT METHOD APPARATUS

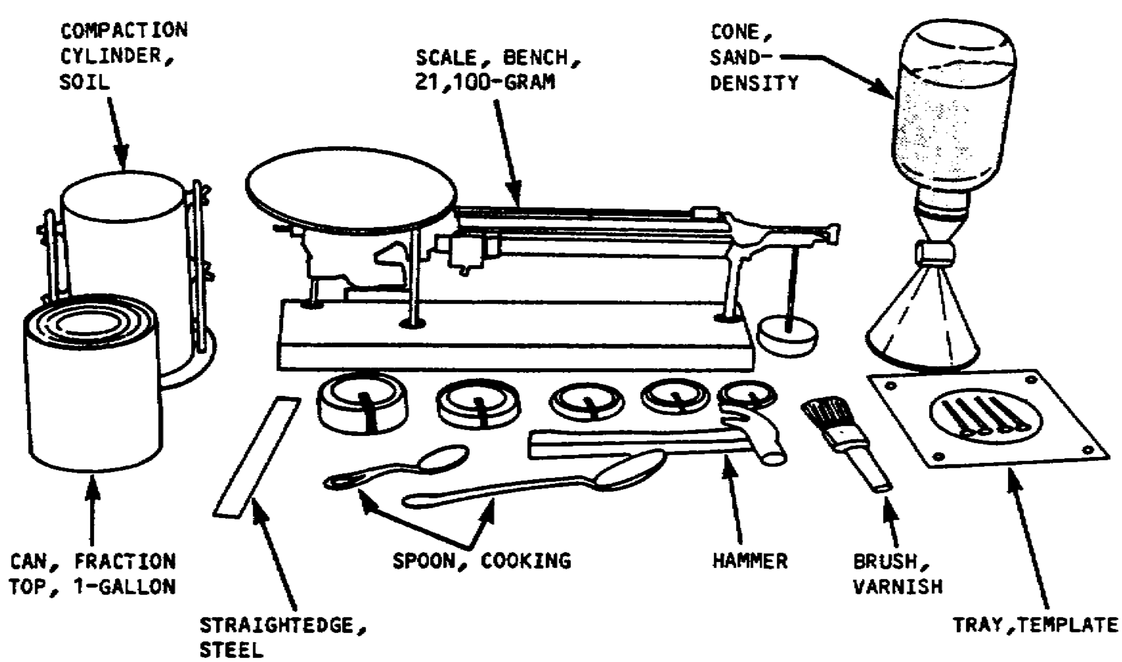


Figure 29 is the front of data sheet, DD Form 1215, you will use to record the data from the disturbed sample methods. In this case, the data is from tests using the sand displacement method.

FIGURE 29. DD FORM 1215 (Front)

UNIT WEIGHT DETERMINATION "VOLUME OF HOLE" METHODS		DATE 2 APR 1986
PROJECT HIGHWAY #203	TEST SITE ℄ STA 50+00 ℄ STA 52+00	SAMPLE NUMBER 203-6 203-7

ADDITIONAL SPECIFICATIONS

FILL COMPACTION

CONVERSION FACTORS

1 in. = 2.54 cm. 1 gm/cc or 62.4 lb/cu. ft. = Unit weight of water

1 lb = 453.6 gm. 1 cu ft = 1728 cu. in.

CALIBRATION OF STANDARD MATERIAL — STANDARD MATERIAL (Check one): ☒ SAND ☐ OIL ☐ OTHER (Specify)

	UNITS				
APPARATUS OR TARE NUMBER		1	1		
1. WEIGHT OF APPARATUS OR TARE FILLED	gm	12530	SAME		
2. WEIGHT OF APPARATUS OR TARE EMPTY	gm	3711			
3. WEIGHT OF MATERIAL (1.-2.)	gm	8819			
4. VOLUME OF APPARATUS OR TARE	cu ft	.2048			
5. UNIT WEIGHT OF MATERIAL (3/4)	lb/cu ft	94.9			
6. AVERAGE UNIT WEIGHT OF MATERIAL	LB/CU FT				

CALIBRATION OF APPARATUS

	UNITS	TEMPLATE NUMBER 203-6	203-7	CONE NUMBER	
7. INITIAL WEIGHT OF APPARATUS + SAND	gm	12530	12518		
8. FINAL WEIGHT OF APPARATUS + SAND	gm	10931	10897		
9. WEIGHT OF SAND IN TEMPLATE AND/OR CONE	gm	1599	1621		

"VOLUME OF HOLE"

	UNITS				
10. INITIAL WEIGHT OF APPARATUS + MATERIAL	gm	10931	10897		
11. FINAL WEIGHT OF APPARATUS + MATERIAL	gm	6608	6631		
12. WEIGHT OF MATERIAL RELEASED (10.-11.)	gm	4323	4266		
13. WEIGHT OF MATERIAL IN HOLE (For oil, same as 12. For sand, 12.-9.)	gm	2724	2645		
14. VOLUME OF HOLE (13/6.)	cu ft	.0632	.0614		

FIGURE 30. DD FORM 1215 (Back)

WATER CONTENT DETERMINATION

	UNITS	203-6		203-7			
TARE NUMBER		12		15			
15. WEIGHT WET SOIL & TARE	gm	4340		4170			
16. WEIGHT DRY SOIL & TARE	gm	4152		3995			
17. WEIGHT WATER (15.-16.)	gm	188		175			
18. WEIGHT TARE	gm	276		273			
19. WEIGHT DRY SOIL (16.-18.)	gm	3886		3722			
20. WATER CONTENT (17/19 x 100)	%	4.9		4.7			
21. AVERAGE WATER CONTENT	PERCENT	4.9		4.7			

UNIT WEIGHT DETERMINATION

	UNITS	203-6	203-7	
TARE NUMBER		12	15	
22. WEIGHT WET SOIL & TARE	gm	4340	4170	
23. WEIGHT TARE	gm	276	273	
24. WEIGHT WET SOIL (22.-23.)	gm	4064	3897	
25. WET UNIT WEIGHT (24./14.)	LB /CU FT	142.0	139.8	
26. DRY UNIT WEIGHT (25. x 100/(100+21).)	LB /CU FT	135.1	133.7	

REMARKS

SPEC. DRY DENSITY 132 LB/CU FT.

TESTS O.K.

L. Thomas

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)
Paul Massein	Paul Massein	L. Thomas

- Empty the water from the apparatus.
- Repeat the second through the sixth steps, at least two or more times.
- Compute the volume of the apparatus by averaging the measured weights, converting the average to pounds (divide by 453.6 g/lb), and converting the average weight in pounds to volume (divide by 62.4 pounds per cubic foot). The result is the volume in cubic feet. Note the example of the computation in Figures 29 and 30.

Sand Calibration. The Bulk Density of Sand is Affected by Changes in Temperature and Humidity.

Sand calibration must be checked prior to each test. Use a container of known volume, such as the Proctor mold. The mold with base plate attached is weighed empty. Attach the collar and place the sand cone with the valve open on top. Pour the sand from about the same height that it will fall in a field-dug hole and allow it to fall at its own rate into the mold. When the sand stops running into the mold, close the valve on the cone. Carefully remove the sand cone and the mold collar using a straight edge. Strike off the excess sand remaining on top of the mold. Brush off any sand adhering to the outside of the mold. Weigh the mold, full of sand. Repeat the entire process and average the two weights (mold full of sand). Subtract the weight of the empty mold from the average of the full weights. The difference in weights divided by the known volume of the container is equal to the density of the sand.

Surface Calibration

One more calibration must be made prior to starting the test. However, it is performed after the surface is prepared and the template tray is in place.

Test Procedure

Setting the Template. Prior to the test, take a soil sample directly from the ground. The ground surface where the density is to be determined is prepared by clearing and leveling. No attempt should be made to smooth the surface with a spatula, trowel, or other tool. Place the template tray shown in Figure 18 flush on the surface. Seal any spaces on the inside edge under the plate with modeling clay. Force nails through the holes in the tray to hold it firmly in position.

Surface Calibration. As mentioned above, the surface irregularities inside of the metal tray must be accounted for. To do this, check the volume of the space between the inner surface of the upper cone and the test surface.

- Use the apparatus with its sand fill for this calibration.
- With the valve closed, turn the apparatus over, large cone down, and place it over the hole in the metal tray. Be careful not to jar or shake the container and cause packing of the sand.

- Open the valve carefully and permit the sand to fill the space under the cone.
- Close the valve and weigh the apparatus and remaining sand. Record this weight (line 8, Figure 19). The difference in weight between the starting and final values (lines 7 and 8) is the weight of sand in the tray and cone (line 9).
- After making the calibration, recover as much of the sand from the tray as feasible without disturbing the tray or the soil in the hole. Brush the remaining sand particles lightly from within the tray.

Digging the Sample. The next procedure is to dig into the soil through the center hole in the tray. A hole is required which is about six inches deep and approximately the same diameter as the hole in the tray. The digging of samples in nonplastic coarse-grained soils is difficult, especially in keeping the walls of the hole undisturbed. Driving a chisel or other tool with a hammer should not be tried unless no other method works and then only near the center of the hole. Keep the inside of the hole as free of pockets and sharp protruberances as possible. Coarse-grained material with plastic fines or fine-grained soils are easier to dig. Take care to remove all loose particles from the hole and to see that all the removed particles are included in a container whose weight has been previously determined and recorded. Weigh the sample and container immediately and record the weight. Keep the lid on the container as much as possible to prevent excessive moisture loss until it can be weighed. Mark the container for later identification when the soil moisture content is determined.

Volume-of-Hole Determination

After removing the soil sample from the hole, proceed as follows:

- Place the sand-cone apparatus on the metal plate over the hole. Do not jar or shake the container to cause compaction of the sand.
- Open the valve and allow the sand to fill the hole in the ground and space under the cone.
- When the sand stops flowing, close the valve, remove the apparatus, and weigh it and the remaining sand. Record this weight (line 11, Figure 31).

The weight of the sand required to fill the hole equals the weight of the apparatus and sand (line 8 transferred to line 10) minus the final weight (from item above) and minus the weight of sand in the template and cone (line 9).

FOR INSTRUCTIONAL PURPOSES ONLY

FIGURE 31. DD FORM 1215 (Back)

WATER CONTENT DETERMINATION

	UNITS	203-6		203-7			
TARE NUMBER		12		15			
15. WEIGHT WET SOIL & TARE	gm	4340		4170			
16. WEIGHT DRY SOIL & TARE	gm	4152		3995			
17. WEIGHT WATER (15.-16.)	gm	188		175			
18. WEIGHT TARE	gm	276		273			
19. WEIGHT DRY SOIL (16.-18.)	gm	3886		3722			
20. WATER CONTENT ($\frac{17}{19}$ × 100)	%	4.9		4.7			
21. AVERAGE WATER CONTENT	PERCENT	4.9		4.7			

UNIT WEIGHT DETERMINATION

	UNITS	203-6	203-7	
TARE NUMBER		12	15	
22. WEIGHT WET SOIL & TARE	gm	4340	4170	
23. WEIGHT TARE	gm	276	273	
24. WEIGHT WET SOIL (22.-23.)	gm	4064	3897	
25. WET UNIT WEIGHT (24./14.)	LB/CU FT	142.0	139.8	
26. DRY UNIT WEIGHT (25. × $\frac{100}{100+21}$)	LB/CU FT	135.1	133.7	

REMARKS

SPEC. DRY DENSITY 132 LB/CU FT.

TESTS O.K.

L. Thomas

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)
Paul Massion	Paul Massion	L. Thomas

The volume of the hole is computed by dividing the weight of sand in the hole by the calibrated density or unit weight (line 6).

Density Determination

With the volume of the hole computed the remaining requirements are the moisture content and the dry weights of the soil sample.

The container with the sample is oven-dried, air-cooled, and weighed. Record this weight on the reverse side of the form, line 16. The difference (line 15 - line 16 = line 17) is the weight of water in the sample. Subtracting the tare weight (line 18) from the dry soil and tare weight (line 16) results in the weight of dry soil (line 19). Moisture content (line 10) is the weight of water (line 17) divided by the dry weight (line 19) and expressed as a percentage.

If drying the entire sample and the container is not possible, an alternate but less desirable method may be used. A specimen selected from the container is weighed and oven-dried. Using the weight of the specimen and the entire sample, determine a percentage and translate the dry weight of the specimen to get the dry weight of the entire sample.

Compare the wet density or unit weight (line 25) by dividing the wet soil weight (line 24) by 453.6 to convert the grams to pounds, and then by the volume of the hole (line 14). The dry density or unit weight is computed as follows:

$$\text{dry density} = \frac{\text{wet density}}{1 + \left(\frac{\text{moisture content}}{100}\right)} = \frac{\text{wet density}}{1 + (w/100)} = \text{lbs/ft}$$

The sand cone method is the preferred technique of the Army. However, there is a problem when time is important because this method takes 25 minutes or more per test.

OTHER METHODS

There are numerous other methods for determining the density of the in-place soil. These include the use of the water-balloon, oil, or paraffin coated box or cylinder specimens. These methods generally use the identical principle of volume determination by the displacement of a known density material. Therefore, it does not really matter what material is utilized as long as its density characteristics are known or can be established.

The oil displacement method cannot be used on pervious soils which will absorb the oil quickly. Also, residual oil spillage in a construction area will tend to soften asphaltic concrete placed in the area.

Learning Event 4
DESCRIBE USES OF THE NUCLEAR MOISTURE AND DENSITY GAGE

The nuclear moisture and density gage is a device that measures density and moisture contents of soil, asphalt, and other materials. It is used extensively by engineers because of its labor saving advantage. It is quick and provides accurate values, equal to present standard methods.

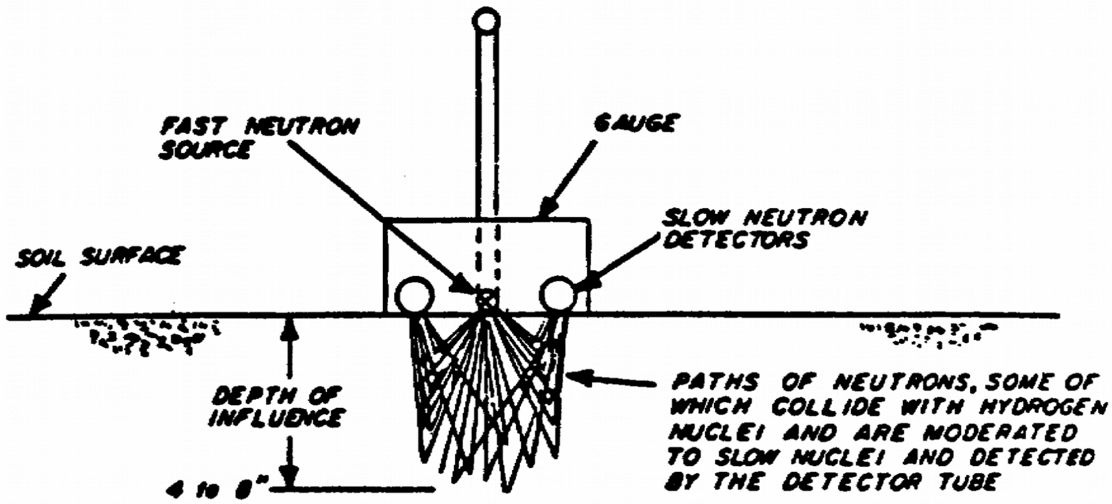
The nuclear device has gamma and neutron radiation sources. The gamma source measures density. The less dense a soil, the less gamma radiation feedback occurs. The neutron radiation measures hydrogen content. The neutron source will detect hydrogen elements within an object. (An example is water (H_2O) within a soil mass.) The more hydrogen detected, the higher the neutron reading. However, organics can cause neutron readings to be inaccurate. Organics like decomposed trash, rotting trees, topsoil, leaves, and algae can cause inaccuracies to the nuclear device readings.

Thus, to be used properly, the nuclear device must be handled by experienced, qualified personnel. Handled properly, it is a safe and time efficient device that allows engineers to get adequate and immediate density and moisture content readings on the project site.

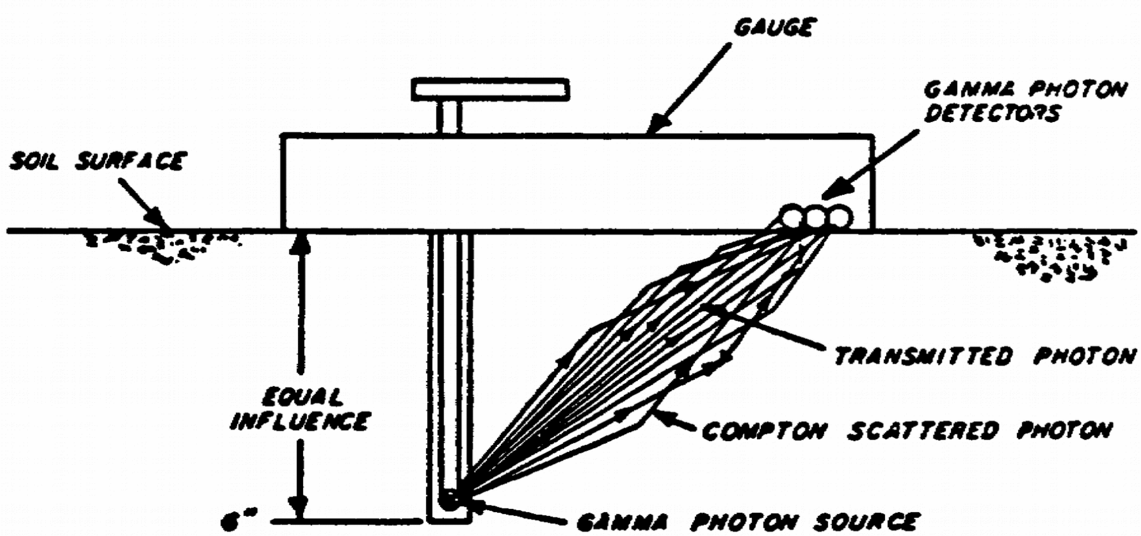
See Figure 32 following.

FIGURE 32. NUCLEAR MOISTURE AND DENSITY GAUGE

Backsetter Moisture Measurement



Direct Transmission Density Measurement



Learning Event 5
IDENTIFY CORRECTIVE ACTIONS FOR DISCREPANCIES

Discrepancies between the moisture and density in-place and the desired moisture and density ranges probably mean that you will have to take corrective action. Your decision will depend on the overall series of test results as well as economic considerations. If large variations occur, they may indicate a situation which could lead to differential settlement. In such a case, corrective action is necessary. However, if you have tested every 100 feet and one test varies slightly, corrective action is not economically logical.

Determining How Much Water Must be Added for Optimum Moisture

If the moisture content of the soil is less than optimum, the amount of water which must be added for efficient compaction generally is computed in gallons per 100 feet of length (station). The computation is based upon the dry weight of soil contained in a compacted layer. For example, assume that the soil is to be placed in layers 6 inches in compacted thickness at a dry unit weight of 120 pounds per cubic foot. The moisture content of the soil is determined to be 5 percent, while the optimum moisture content is 12 percent. Assume that the strip to be compacted is 40 feet wide. Compute the amount of water which must be added per 100-foot station to bring the soil to optimum moisture. The following formula will apply:

$$\frac{\begin{array}{c}\text{Desired dry}\\ \text{Density of Soil}\end{array} \times \begin{array}{c}\text{Percentage Moisture}\\ \text{to Be Added}\end{array} \times \begin{array}{c}\text{Earth Volume}\\ \text{(Cubic Feet)}\end{array}}{830} = \begin{array}{l}\text{Gal. to be added}\\ \text{per 100 feet}\end{array}$$

Substituting in the above formula from the conditions given:

$$\frac{120 \times (12 - 5) \times 40 \times 100 \times 0.5}{830} = 2024 \text{ gallons per 100 feet}$$

If either drying conditions or rain conditions exist at the time work is in progress, it may be advisable to either add to or reduce this quantity by up to 10 percent.

Determining Density Adjustments

Density determinations are made in the field by measuring the wet weight of a known volume of compacted soil as described earlier. The sample to be weighed is taken from a roughly cylindrical hole which is dug in the compacted layer. The volume of the hole may be determined by one of several methods, including the use of heavy oil of known specific gravity, the rubber balloon density apparatus, water which is poured into a thin sheet of rubber which lines the inside of the hole, and calibrated sand. Knowing the wet weight and the volume, the unit wet weight may then be calculated.

FREQUENCY OF DENSITY CHECKS

If the density determined by the methods described above is equal to or greater than that required, then rolling generally may be judged to be satisfactory and the placing of another lift may proceed. If the density is lower than that required, additional rolling may be necessary or the moisture content may have to be adjusted. If these measures fail, then the weight of the roller may have to be increased, the thickness of lift reduced, or some other measure taken to obtain adequate compaction. Never overlook the possibility that the soil which is being rolled in the field is not the same one which was tested in the laboratory. Under normal field conditions the number of density and moisture checks required should not be very great after the initial period of adjustment, assuming that the work is proceeding smoothly and the same soils being compacted. If adequate densities are being obtained and the proper moisture content is being maintained, the job of inspection may then be principally one of keeping to the set number of passes and combinations of the rollers which will achieve the desired result. Where conditions vary more, density and moisture checks may be needed more often for a fill of even moderate length. The exact number of checks needed can only be determined by the engineer in charge of the job.

INFLUENCE OF MOISTURE CONTENT

For a given weight and given compaction effort, the moisture content determines the state at which maximum dry unit weight (density) occurs. When moisture content is low, the soil is stiff and difficult to compress; low values of dry unit weight and high values of air content are obtained. As the moisture content is increased, the added water decreases surface tension and acts as a lubricant causing the soil to soften and become more workable, resulting in a high unit weight and lower air content. The optimum moisture content at which maximum dry density is attained is the moisture content at which the soil has become sufficiently workable: that under compaction effort used, it has permitted the soil to become packed so closely as to expel most of the air. As the moisture content is increased above the optimum, the soil becomes increasingly more workable, but the increased moisture content and the remaining unexpelled air fill the soil voids and prevent close consolidation.

LEAD-THROUGH PRACTICAL EXERCISE
FIELD DENSITY (SAND METHOD)

SITUATION: The density of a compacted base course for an airfield being constructed in the Theater of Operations was checked by means of the sand method.

A. The following data was obtained in calibrating the sand to be used in the field density test.

Trial Number	1	2
Weight of Sand Required to Fill Proctor Compaction Mold Plus Weight of Mold	12.65 lbs	12.61 lbs
Weight of Proctor Mold	9.70 lbs	9.70 lbs
Volume of Proctor Mold	0.033 cu. ft.	0.033 cu.

From the calibration data, what is the unit weight of the sand to be used in the field density test when:

1. Average Weight of Sand Plus Mold = 12.63 lbs
2. Average weight of Sand in Mold = 2.93 lbs
3. Unit Weight = Weight/Volume =

____________ lbs/cubic ft

B. In the field, 7.62 pounds of wet soil was removed from the compacted subbase. Results from the alcohol method of rapid water content determination showed the soil has a water content of 13.6 percent. In addition, it took 4.83 pounds of the calibrated sand to fill the hole from which the compacted subbase sample was taken.

1. What was the volume of the compacted subbase sample when:

$$\text{Volume} = \frac{\text{Weight of Sand Poured into Hole}}{\text{Density of Sand Used}} =$$

__________ cubic ft

2. What is the wet unit weight of the compacted subbase when:

$$\text{Wet Unit Weight} = \frac{\text{Weight of Wet Soil Removed From Hole}}{\text{Volume (which it occupied)}} =$$

__________ lbs/cubic ft

3. What is the dry unit weight of the compacted subbase when:

$$\text{Dry Unit Weight} = \frac{\text{Wet Unit Weight}}{1 + (\text{percent water content}/100)} =$$

__________ lbs/cubic ft

C. The maximum CE 55 dry unit weight for this soil is 130 lbs/cubic ft. What percentage of the 100 percent density specification was obtained in the compacted subbase when:

$$\text{Percentage Compaction} = \frac{\text{Dry Density Obtained in the Field}}{\text{100\% of Laboratory Density}} \times 100 =$$

________ percent

LEAD-THROUGH PRACTICAL EXERCISE SOLUTION

A. 3. Unit Weight $= \dfrac{2.93}{0.033} = 88.8$ lbs/cubic ft.

B. 1. Volume $= \dfrac{4.83}{88.78} = 0.054$ cubic ft.

2. Wet Unit Weight $= \dfrac{7.62}{0.054} = 141.1$ lbs/cubic ft

3. Dry Unit Weight $= \dfrac{141.1}{1.13} = 124.2$ lbs/cubic ft

C. Percentage Compaction $= \dfrac{124.2}{130} = 95.5$ percent

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Lesson 4/Practice Exercise

PRACTICE EXERCISE FOR LESSON 4

Instructions

Check your understanding of Lesson 4 by completing the practice exercise. There is only one correct answer to each question. Try to answer all of the questions without referring to the lesson materials.

When you have completed all of the questions, turn the page and check your answers against the correct responses. Each correct response is referenced to specific portions of the lesson material so that you can review any questions you have missed or do not understand, before continuing to the next lesson.

1. The __________ is an expedient method of moisture testing, but it should be repeated several times for the most accurate results.
   a. oven method.
   b. shear penetration test.
   c. alcohol burn-off method.
   d. undisturbed sample method.

2. It can be time-consuming and troublesome to take a chunk sample, but if you have the time it can contribute important data to the soils analysis. However, you will not be able to take chunk samples in __________ soils.
   a. clay-like
   b. coarse-grained
   c. cohesive
   d. cohesionless

3. Using the sand cone method of in-place testing, you must make three calibrations: apparatus, sand, and surface. If the sand is uniformly graded, why calibrate it before each test? __________

   ____
   _

4. What is the primary advantage of the nuclear moisture and density gage over the sand cone method? ____

   ____
   _

5. The two liquid displacement methods, oil and water, are similar in procedure. Which one cannot be used on pervious soils, or in a construction area where asphalt will be used? ______________

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ANSWER SHEET FOR PRACTICE EXERCISE

Lesson 3		**Learning Event**
1.	c. Alcohol burn-off method	1
2.	d. cohesionless	2
3.	The bulk density of sand is affected by changes in temperature and humidity.	3
4.	It takes less time than the sand cone method.	3 and 4
5.	Oil displacement method	3

Lesson 5
CALIFORNIA BEARING RATIO

TASK: Determine Soil Strength of Non-swelling, Swelling, and Free-draining Soils Using CBR

CONDITIONS: Given this subcourse, a No. 2 Pencil, paper, and an ACCP Examination Response Sheet.

STANDARDS: Demonstrate competency of the task skills and knowledge by responding correctly to 75% of the examination questions.

CREDIT HOURS: 2

REFERENCE: FM 5-530

Lesson 5/Learning Event 1

INTRODUCTION

Airfields and roads are designed from the subgrade up. Each layer of soil has a particular name depending on where it is placed in the flexible pavement. The actual "name" and "thickness" of each layer is dependent on the soil's California Bearing Ratio (CBR) Value. CBR is a measurement of the shearing resistance of the soil, i.e., soil strength. The higher the CBR, the stronger the soil. Most soils usually fall between CBR values of 1 (swamps) to 100 (gravels).

The shearing resistance is related to a soil's ability to withstand load, and it is especially important for a soil which is used as a base or subgrade beneath a road surface, an airfield runway, or any other structure. With the CBR method, the shearing resistance of the soil is measured under controlled conditions of density and moisture. Once the design strength (CBR) is found, construction must be accomplished within certain moisture and dry densities to achieve this strength.

Learning Event 1
APPLY PRINCIPLES OF PAVEMENT DESIGN USING THE CBR METHOD

Soils display variation in dry densities when compaction occurs at different magnitudes and at different soil moisture content. Intuitively, this means different strengths are obtainable at various combinations of soil moisture and levels of compactive effort. For some soils, the moisture content which gives the greatest dry density also gives the greatest strength. The generalization, more density gives more strength, does not hold for all cases. The object of the CBR Test Program is to define in the laboratory the soil placement conditions (moisture content and dry density) which gives the greatest measure of strength.

Prior to defining a test program, the engineer should have a basic understanding of the principles of pavement design using the CBR method. Figure 33 is a sketch of a typical flexible pavement upon which the design wheel load has been imposed. As indicated by the dashed line, the stresses caused by this load are dissipated with depth into the pavement structure. This means the further a soil is beneath the load, the less soil strength (lower CBR) is required to support that load. The pavement design curves allow for determination of thickness or protective cover required to keep each layer of material from failing under the imposed load. In making a design, the engineer must determine the strength of the soil and the associated field control measures, namely, soil placement moisture content ranges and compaction ranges which insure a design strength. Also of note is the fact that design specifications impose minimum levels of compaction (as shown in Table 8) which serve to minimize settlement under traffic loads. As indicated in both Figure 33 and Table 8, the soils in a flexible pavement have been named depending upon their strength and/or use within the structure.

FIGURE 33. TYPICAL FLEXIBLE PAVEMENT SECTION

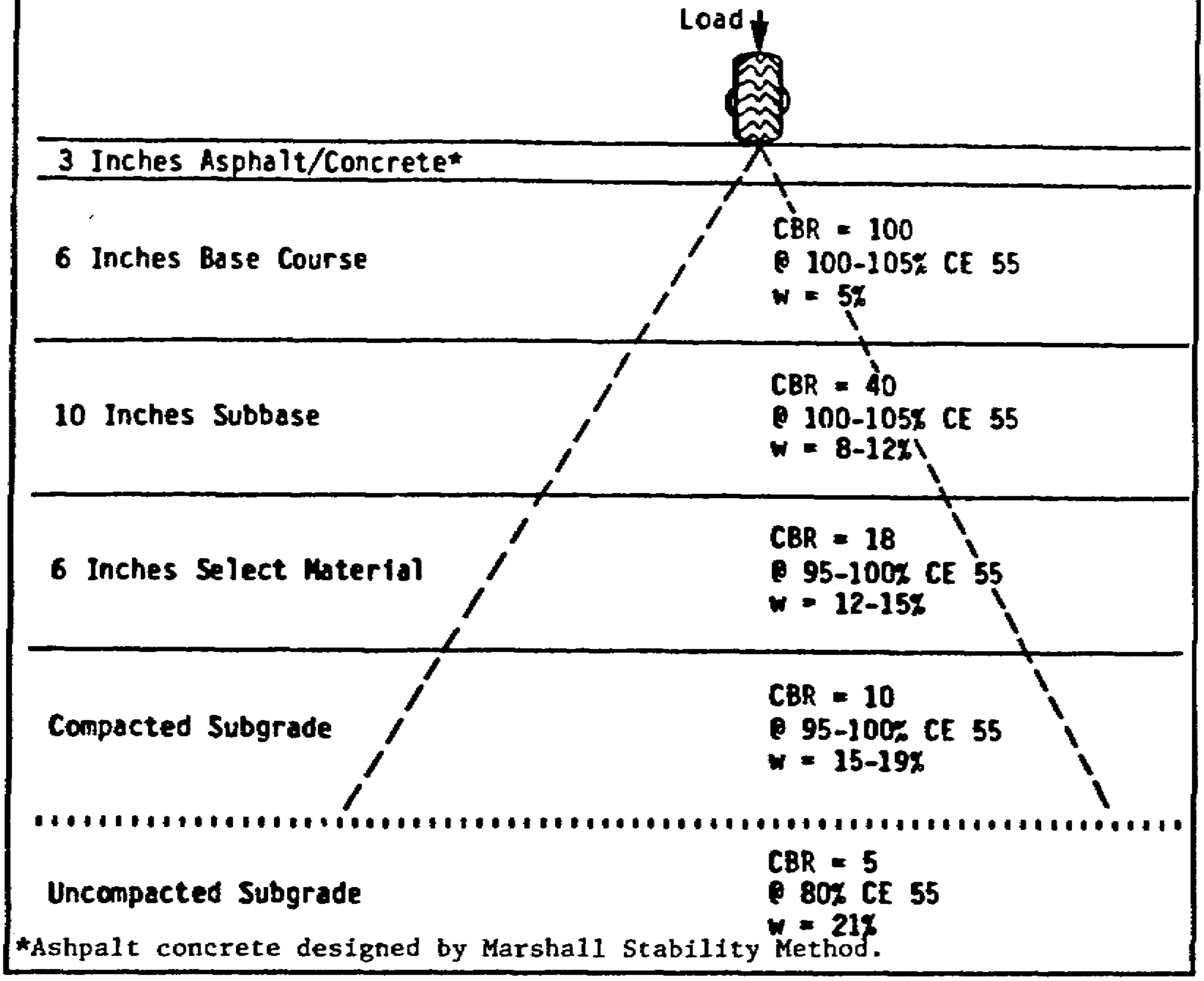


TABLE 8. SUMMARY OF COMPACTION REQUIREMENTS

Material	Percentage Compaction of Materials with Design CBR Values of 20 and Above
Base Course	No less than 100 percent of CE 55 maximum density.
Subbase and Subgrade	No less than 100 percent of CE 55 maximum density.
	Percentage Compaction of Materials with Design CBR Values Below 20
Select Material and Subgrade in Fills	Cohesionless fill will not be placed at less than 95 percent of CE 55 maximum density. Cohesive fill will not be placed at less than 90 percent of CE 55 maximum density.

NOTE: A cohesive soil is one with a PI above 5.
A cohesionless soil is one with a PI of 5 or below.

Starting at the bottom of the pavement and moving toward the surface, a brief description of the components follows.

Subgrade. Subgrade is the in-place natural soil which supports the pavement structure. It may have a CBR value ranging from 0 to 100 percent and specifications require that portions of it must be compacted.

Select Materials. Select material is occurring imported soil having CBR values less than 20 percent but greater than the compacted subgrade. It is used to carry stress levels intermediate to those supported by the subgrade and subbase material.

Subbase Material. Subbase material is imported cohesionless material having CBR values ranging from 20 to 50 percent. It is normally obtained from natural gravel deposits and serves to carry intermediate stresses in the pavement.

Base Course

Base course is highest quality structural materials having strengths of nearly 100 percent CBR. For pavement design, CBR values are normally assigned based upon gradation requirements rather than CBR tests. Base course are always cohesionless and usually processed to obtain the desired gradation.

Asphalt Concrete

This is material that serves primarily as a wearing course and moisture barrier. It provides structural strength to the pavement and is designed using the Marshall Test Method rather than CBR.

FACTORS AFFECTING TYPE OF TEST PROGRAM

The type of test program and the analysis of the resulting data depends on: (1) where the soil is going to be used in the pavement; (2) whether or not the soil will be disturbed during the construction process; (3) the level of compactive effort required to preclude settlement; and (4) the physical nature of the soil. From Figure 33 it can be seen that the materials above the uncompacted subgrade will undergo considerable disturbance and the laboratory test used to define strength must reflect this fact. Likewise, a test method that gives strengths for undisturbed samples should be used for the uncompacted subgrade.

The nature of the soil will determine the amount and type of laboratory work required. For example, coarse-grained, free-draining soils or those soils having few fines may display little strength variation with changes in moisture content while some fine-grained soils show objectionable volumetric changes (swelling) as the molding moisture content varies. Table 9 is a summary of the test methods which should serve as a guide for the following discussion. However, the basic principle underlying this categorization is simulation of the conditions to which a soil is subjected during both construction and the life of the structure.

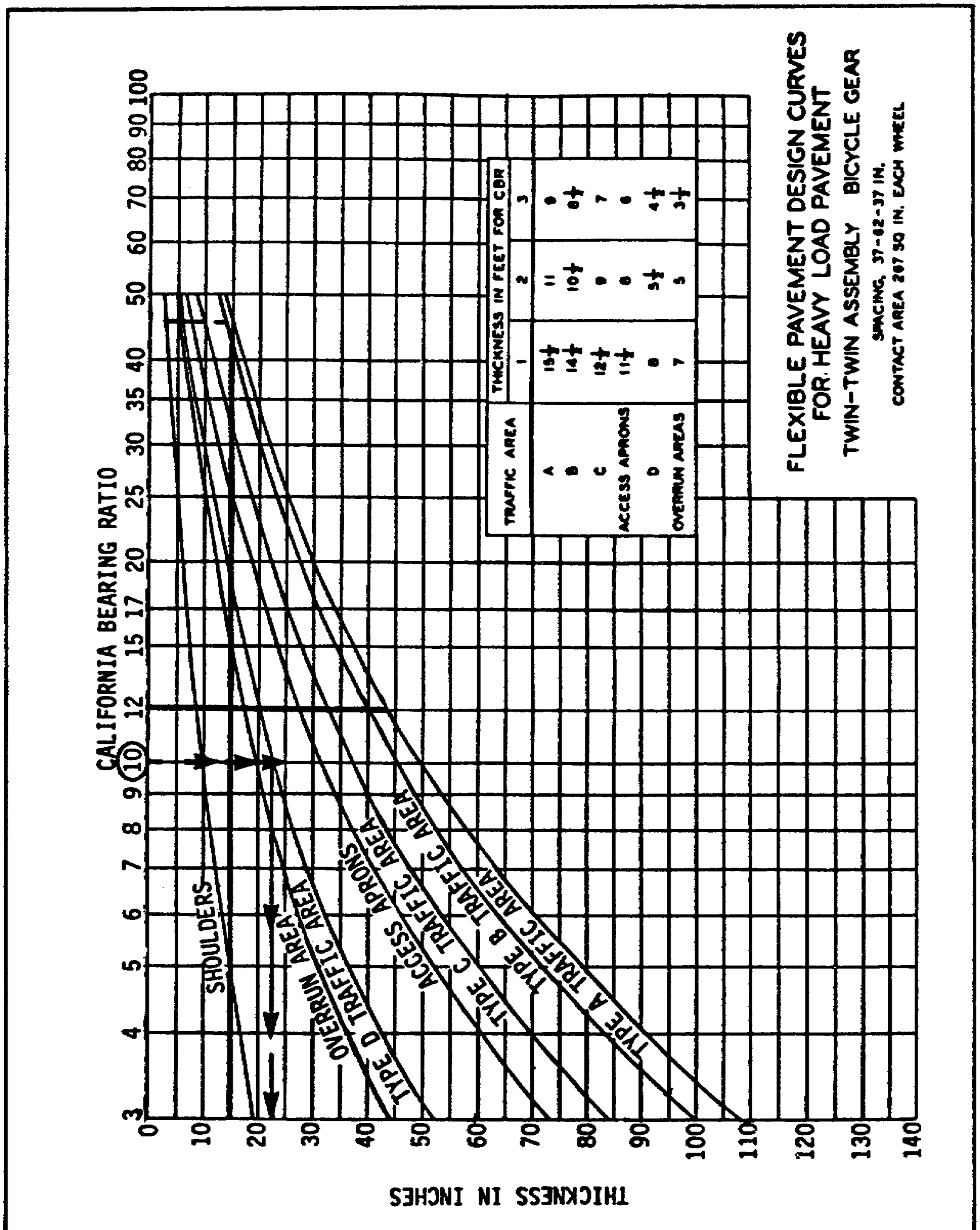
TABLE 9. SUMMARY OF CBR TEST PROGRAMS

Test Program	Type Soil Normally Tested*	Compaction Blows/Layer	Probable Use of Test Results
	REMOLDED LABORATORY TESTS		
Non-Swelling Soils	All except CH, MH, OH, GW, GP, SW, and SP	For CBR > 20 26, 55, 72 For CBR < 20 12, 26, 55	For compacted subgrade, select, and subbase materials
Swelling Soils	CH, MH, and OH	12, 26, 55	Low quality compacted subgrades
Free-Draining Soils	GW, GP, SW, and SP	26, 55, 72	Compacted subgrade, select and subbase materials
	TESTS FOR IN SITU STRENGTHS		
Field CBR	All	N/A	Uncompacted subgrade
Undisturbed Sample	CH, MH, and OH	N/A	Uncompacted subgrade--allows evaluation of swell

* This categorization is intended to serve as a guide for planning laboratory activities. Deviations may be noted in the initial stages of a test program which will dictate adjustments.

The use of CBR in designing a flexible pavement is illustrated in Figure 34. As an example, the compacted subgrade in Figure 33 has a CBR value of 10. To find the value for Type D Traffic area, read down from 10 and across to determine that 22 inches of pavement is required above the compacted subgrade (this is for twin assembly, bicycle gear, heavy load pavement).

FIGURE 34. FLEXIBLE PAVEMENT DESIGN CURVES



Learning Event 2
DESCRIBE CBR TESTS WITH APPLICATIONS, ADVANTAGES, AND DISADVANTAGES

Since 1940, the Corps of Engineers has performed continuous investigations relative to flexible pavement design. Although the CBR method of design is considered a semi-empirical approach where each of the factors relating to a soil's ability to resist traffic loads has not been individually analyzed, its worth as a design method lies in the fact that over 40 years of experience with actual pavement structures have provided the basis for our present design cues.

CBR TESTS AND APPLICATIONS

The CBR is an index of the shearing resistance of soil obtained by forcing a steel piston having a three square inch end area into the soil at a rate of 0.05 inch per minute and measuring the force required to achieve 0.1 and 0.2 inch of penetration. The force obtained is ratioed against the standard test values of 3000 and 4500 pounds for a standardized crushed limestone (one which passes the 3/4-inch sieve and is well graded) according to the following expressions:

$$\text{Equation \#1} - \frac{\text{Force at 0.1-inch Penetration}}{\text{3000 lbs}} \times 100 = \text{CRB}_{(.1)}\%$$

$$\text{Equation \#2} - \frac{\text{Force at 0.2-inch Penetration}}{\text{4500 lbs}} \times 100 = \text{CBR}_{(.2)}\%$$

<u>or</u> in terms of stress:

$$\text{Equation \#3} - \frac{\text{Stress at 0.1-inch Penetration}}{\text{1000 psi}} \times 100 = \text{CBR}_{(.1)}\%$$

$$\text{Equation \#4} - \frac{\text{Stress at 0.2-inch Penetration}}{\text{1500 psi}} \times 100 = \text{CBR}_{(.2)}\%$$

The basic operations for conducting the CBR test are the same regardless of variations in soil conditions and types of construction.

The test essentially measures the soil resistance to penetration prior to reaching its ultimate shearing value. It is not exactly a measure of the shearing modulus since the confining effects of the molds to exert some influence. The CBR is designated as a ratio in percent from 0 to 100 with a crushed well-graded (pausing through the 3/4-inch sieve) limestone serving as the 100 percent material.

Minor variations in the CBR test will cause wide variations in the results. For this reason, the step-by-step procedures are detailed. Difficulties may still arise. Material with gravel or stones does not yield entirely satisfactory results. You must conduct a number of tests to establish a reasonable average value.

The CBR values range from 0 to 100 depending on the type of soil. The fine-grained soils vary from 3 for organic clays to 15 for micaceous or diatomaceous silts and sands. The sand-silt-clay coarse-grained combinations range from 10 for the clayey mixtures to 40 for the gravelly and silty sands. Gravelly soils range from 20 for the clayey group to 80 for the well-graded gravels and gravel-sand mixtures.

SUMMARY OF SAMPLE PREPARATION

1. Oven-dry the sample at less than 140°F.
2. Determine gradation.
3. Replace all +3/4-inch material with an equivalent weight of material passing the 3/4-inch sieve but retained on the #4 sieve.
4. Compact the sample at the desired moisture content in a CBR mold.
5. Soak for four days and measure swell under surcharge weight.

The object of steps 1 to 3 is to reduce bridging or wedging of large particles in the CBR mold which could cause non-representative compaction results and high CBR values due to relative sizes of piston, particles, and mold diameter. In step 4, an attempt is made to simulate levels of compactive effort and moisture contents obtainable in the field. The soaking (step 5) simulates the worst condition that could befall the soil-complete saturation. The surcharge weight is used to simulate the effort of overlying pavement layers on the soil's strength. It is important to note that many of the procedural steps are of an arbitrary nature which have been compensated for in the flexible pavement design curves. The standardized test procedures must be followed precisely or the test results may be invalid.

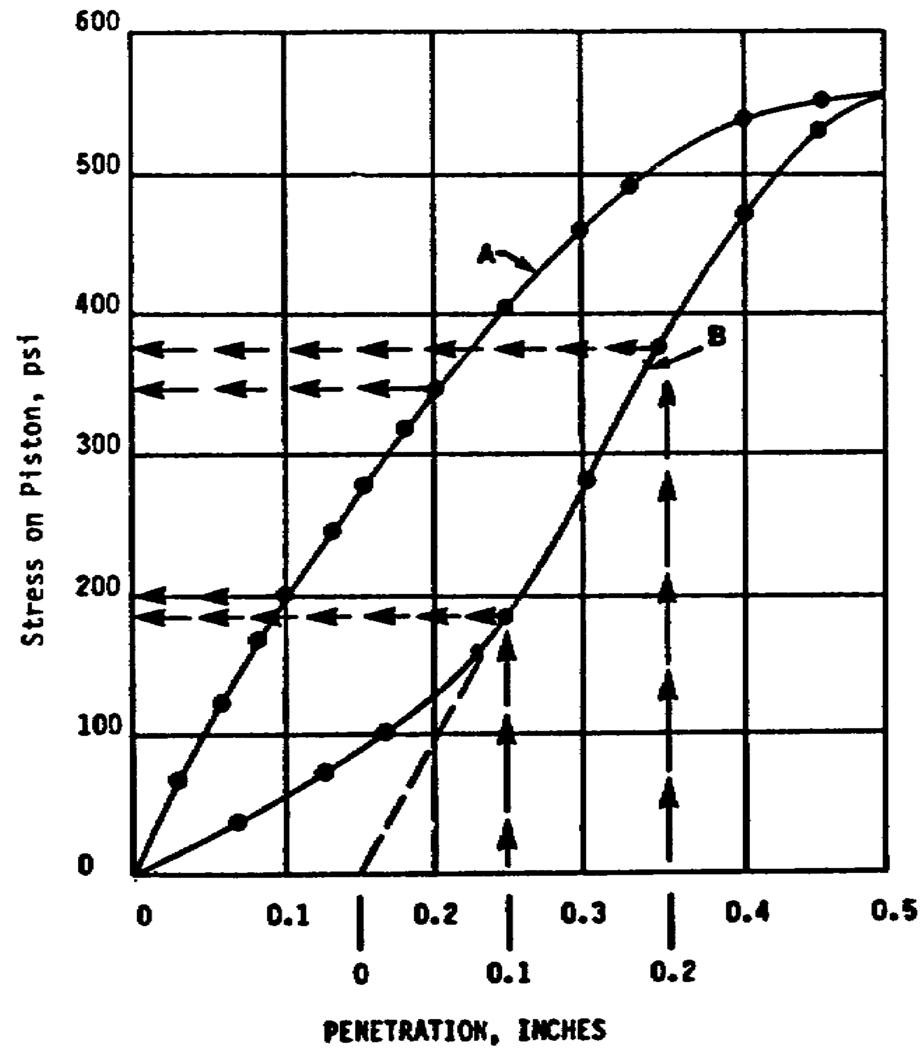
To illustrate the computations required to obtain the CBR value for a soil, the results of two typical penetration tests shown in Figure 35 will be used. Curve A is representative of results from a test in which all went well. Although the stress versus penetration plot is not linear, it does approximate this condition at penetration depths less than 0.30 inch.

At larger penetration depth values, the curve has a decreasing slope indicating plastic failure of the soil. The CBR value is computed by reading the stress values at 0.1 and 0.2 inch penetration and use of equations 3 and 4 as follows:

$$CBR_{(.1)} = \frac{200}{1000} \times 100 = 20 \text{ percent}$$

$$CBR_{(.2)} = \frac{345}{1500} \times 100 = 23 \text{ percent}$$

FIGURE 35. TYPICAL CBR PENETRATION TEST RESULTS



The next question that arises is which value should be used. The larger of the two CBR values is used and should $CBR_{(.2)}$ be the largest it must be verified by testing another sample. This selection criteria implies that:

- Strengths used to design a pavement will be measured at no more than 0.2 inch of soil deformation.
- If $CBR_{(.1)}$ is greater than $CBR_{(.2)}$, the soil sample has begun plastic failure between these limits of deformation and soil strengths obtained at plastic failure will not be used.

- If $CBR_{(.2)}$ is greater than $CBR_{(.1)}$, the soil is still undergoing elastic deformation up to 0.2 inch of penetration and this elastic strength can be used if verified by a second test.

In the preceding example, the appropriate CBR would be 23 percent if verified by a second test.

Curve B in Figure 35 which has a concaved upward shape between 0 and 0.23 inch penetration is a manifestation of surface irregularities resulting from the lack of complete initial contact between the piston and the soil sample surface. Compensation for this fault can be made by extending the straight line portion of the stress/penetration curve until it intersects the abscissa and taking that intersection as the new origin. The stresses at the new 0.1- and 0.2-inch penetrations are shown in Figure 35.

The CBR values are computed by equations 3 and 4. Selection of the specific CBR (i.e., $CBR_{(.1)}$ or $CBR_{(.2)}$) are made using the same guides as for curve A. In this example:

$$\mathbf{CBR_{(.1)}} = \frac{190}{1000} \times 100 = 19 \text{ percent}$$

$$\mathbf{CBR_{(.2)}} = \frac{375}{1500} \times 100 = 25 \text{ percent}$$

The appropriate value would be 25 percent if the test were verified. After determining a CBR value from the penetration data, that value is called the <u>corrected CBR</u> whether or not you have made an adjustment to the original.

The penetration test described above will give a CBR value of the soil at one moisture content and dry density. The strength of the soil under field conditions will vary with variations of moisture and density. Therefore, it is necessary to test the soil under a wide range of moisture and density conditions. Test programs should be selected based on the type of soil being tested and its intended use in the pavement structure. Table 9 gives guidelines for the selection of test programs to fit most situations. The following facts should be kept in mind when developing a testing program.

1. An increase in compactive effort produces an increase in density and a decrease in OMC (where OMC is the optimum moisture content at a specified compaction).
2. The relationship of strength, water content, and density is complex but follows a distinct pattern. Knowledge of this pattern is essential to intelligent design.
3. In general, variations of blows in laboratory tests and variations of passes, foot size, tire pressure, lift thickness, and gross load, produce variations in compactive effort. Proper application of 1 and 2 above can predict the effect of the variations.

ADVANTAGES AND DISADVANTAGES OF THE CBR TEST

Advantages

- The test can be performed by personnel with relatively little experience and training.
- The test is correlated to service behavior and construction methods and has been successfully used for many years.
- The CBR method adapts more quickly to airfield pavement design for immediate use than any other method.
- You can test soil with simple, portable equipment.
- You can run tests in either the field or the laboratory for design, construction control, or evaluation of existing construction.
- The test is primarily intended for subgrades but applicable to a wide range of different materials.
- Testing can be done on samples representative of future water conditions.

Disadvantages

- The laboratory and field compaction methods are not identical. However, comparative tests indicate that reasonable correlation of results can be obtained from field compact materials and samples compacted under similar conditions in the laboratory.
- Because added strength to highly stabilized surfaces such as asphaltic concrete is neglected, the assumption of a completely saturated subgrade condition sometimes results in a too conservative factor of safety.
- Because many of the procedures are of an arbitrary nature, you must run the test to exact standards in order for the design tables to be valid.

Learning Event 3
IDENTIFY CBR STEPS FOR NON-SWELLING, SWELLING, AND FREE-DRAINING SOILS

It is important to remember that CBR values are most useful when the specimens tested duplicate the density and moisture content expected in the field. In general, the most critical condition for most materials exists when the maximum amount of water has been absorbed. For this reason, the CBR test is made on specimens which have soaked for four days and were confined in molds under a surcharge equal to the weight of the planned base and pavement.

SAMPLE TEST PROGRAM FOR NON-SWELLING SOILS

This test program is applicable to the majority of soils used in construction. As Table 9 indicates, soils which fall into this grouping might be used as compacted subgrade, select, or subbase materials depending upon their strengths and location in regard to the construction site.

To illustrate the methodology of evaluating the design CBR, the data given on the CBR analysis sheet for "Hope Road" will be used. We took this data from the subgrade along a proposed road alignment. The object of the following analysis is to determine a soil placement moisture content range for a specified level of compactive effort which gives the greatest assured design CBR. To develop this data, the soils analyst must accomplish the following:

- *Establish the OMC of the soil at 55 blows/layer.* This is done using the standard CE 55 compaction test. For example, OMC = 14 percent. (Remember, the OMC is the peak of curve moisture content for that soil. Thus, a number of tests are done and a compaction curve is developed. From the curve one can find the OMC value for that soil.) See "Molding Water Content," Figure 36.

FIGURE 36. CBR ANALYSIS SHEET, PART 1

PROJECT Hope Road

SOIL CLASSIFICATION CL

LOCATION OF SOIL STA 4+00

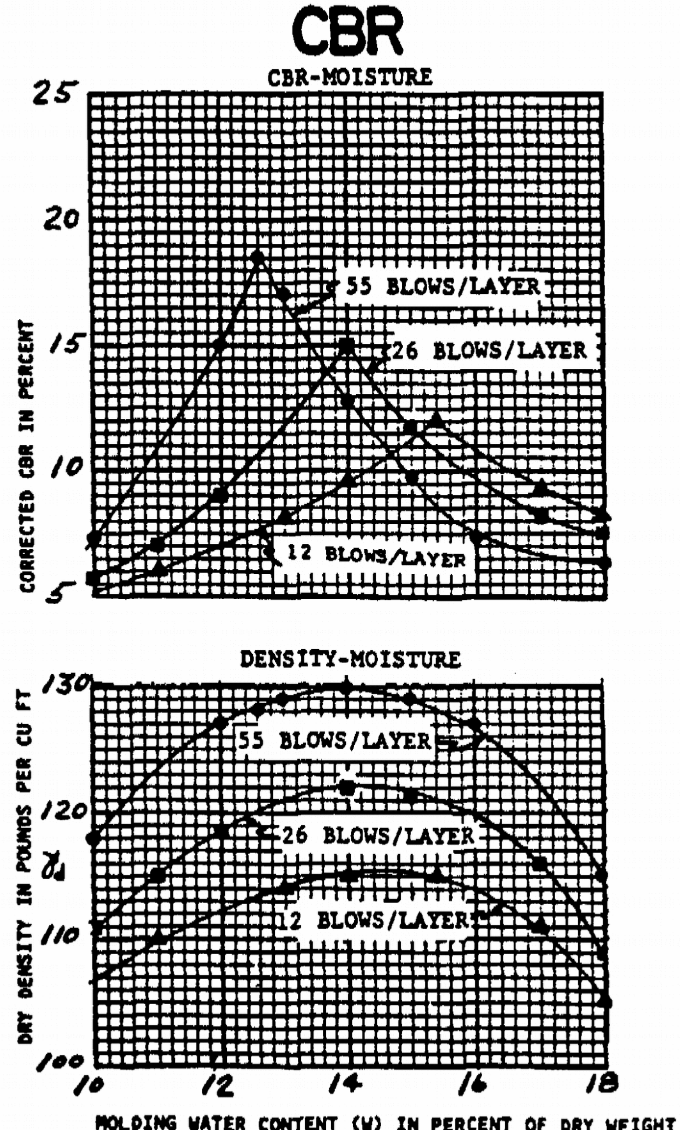
DATE OF TEST 31 June 1984

GROUP # N/A

NAME SP/4 Walker, PFC Drillock

DATA SUMMARY

MOLD #	BLOWS PER LAYER	MOISTURE CONTENT W%	DRY DENSITY	CORRECTED CBR %
1	12	11	110	6.0
2		13	114	8.2
3		14	115	9.5
4		15.4	115	12.0
5		17	111	9.3
6		18	105	8.3
7	26	10	111	5.7
8		11	115	7.0
9		12	118.5	9.0
10		14	122	15.0
11		15	121.5	11.9
12		17	116	8.2
13		18	109	7.6
14	55	10	118	7.4
15		12	127	15.0
16		12.6	128	18.5
17		13	129	17.0
18		14	130	12.8
19		15	129	9.8
20		16	127	7.4
21		18	115	6.4



- *Establish a moisture range for CBR investigation.* OCE Military Standard (2) states that the range is OMC + 4 percent. This is a time-saving guide as experience has shown that the maximum CBR will normally occur at compaction moisture contents within this range and that testing soils behind these limits is wasted effort. For this example, the moisture content range of investigation is 10 to 18 percent.
- *Compact samples within the moisture content range of investigation at different level of compactive effort.* You do this to allow for evaluation of soil strength when field placement is at something other than 100 percent CE 55. The levels of compactive effort to be selected in the laboratory are dependent upon the amount of compactive effort stipulated by the compaction requirements (Table 2). If the soil is expected to be used as compacted subgrade or select material, it will be placed at less than 100 percent CE 55. In this case you select laboratory compactive efforts of 12, 26, and 55 blows per layer.

If the soil is a very high quality subgrade (CBR > 20) or a subbase, the laboratory tests should include samples compacted in excess of 55 blows per layer.* Normally 26, 55, and 72 blows per layer are adequate. The only stipulation placed on the levels of compactive effort to be used is that a 55-blow-per-layer compaction curve be obtained, and that data is developed at two other levels of compactive effort encompassing the specified field placement densities. In this example, the soil is a CL (cohesive) subgrade, so samples were compacted at 12, 16, and 55 blows per layer.

*NOTE: Table 2-4, TM 5-330, is used to estimate whether or not CBR is greater or less than 20.

- *Soak samples and measure swell.* The initial assumption from Table 9 was that this is a non-swelling soil. It is emphasized that this categorization based upon USCS classification is only an approximation. The swell must be monitored to verify the fact that the soil being tested is in fact non-swelling.

Perform CBR penetration tests and determine corrected CBR for each sample. Accumulation of the required data involves a considerable amount of work. At a minimum, 15 molds (five per level of compactive effort) must be made. In this example 21 molds were compacted, the results of which are given in the DATA SUMMARY on the next page.

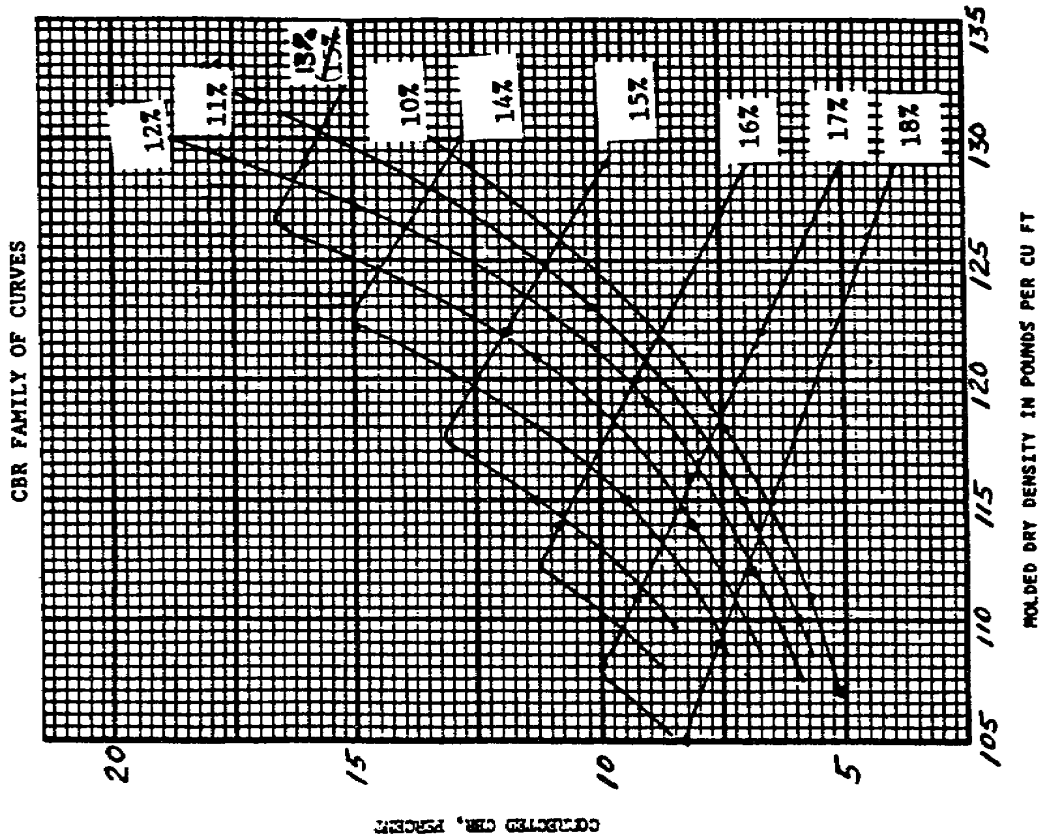
Plot the data on graphs of dry density versus molding moisture content and corrected CBR versus molding moisture content. The example is plotted on the next page.

Reformat data on CBR family of curves data sheet. This is done merely to estimate values of dry density and CBR for whole integer moisture contents within the range of investigation at each level of compactive effort.

Plot the CBR family of curves. The object of this step is to place the laboratory data in a form which lends itself to analysis. You are establishing the trends of strength variation as the moisture content and dry density change. The blank places between actual data points are filled in. Drawing a CBR family of curves involves considerable practice, numerous attempts,

and subsequent adjustments. From the example on the next page (Figure 37) it can be seen that the available data has been plotted on a graph of corrected CBR versus molded dry density for constant moisture contents. For low molding water contents (i.e., from 10 to 12 percent) there was an increase in strength with dry density, and at high moisture contents (i.e., 16, 17, and 18 percent), the reverse was found to be true. For the intermediate moisture contents, there was an increase in strength to some point, and then a decrease as the dry density increased.

FIGURE 37. CBR ANALYSIS, PART 2



CBR FAMILY OF CURVES DATA SHEET

W(%)		12 BLOWS/LAYER	26 BLOWS/LAYER	55 BLOWS/LAYER
10	γ_d CORR	107 LBS/FT³	111 LBS/FT³	118 LBS/FT³
	CBR	5.2 %	5.7 %	7.4 %
11	γ_d CORR	110 LBS/FT³	115 LBS/FT³	123 LBS/FT³
	CBR	6.0 %	7.0 %	10.2 %
12	γ_d CORR	112 LBS/FT³	119 LBS/FT³	127 LBS/FT³
	CBR	7.0 %	9.0 %	15.0 %
13	γ_d CORR	114 LBS/FT³	121 LBS/FT³	129 LBS/FT³
	CBR	8.2 %	11.5 %	17.0 %
14	γ_d CORR	115 LBS/FT³	122 LBS/FT³	130 LBS/FT³
	CBR	9.5 %	15.0 %	12.8 %
15	γ_d CORR	115 LBS/FT³	122 LBS/FT³	129 LBS/FT³
	CBR	11.3 %	11.8 %	9.8 %
16	γ_d CORR	114 LBS/FT³	120 LBS/FT³	127 LBS/FT³
	CBR	10.8 %	9.2 %	7.4 %
17	γ_d CORR	111 LBS/FT³	116 LBS/FT³	122 LBS/FT³
	CBR	9.3 %	8.2 %	6.7 %
18	γ_d CORR	105 LBS/FT³	109 LBS/FT³	115 LBS/FT³
	CBR	8.3 %	7.6 %	6.4 %

ENGINEERING ANALYSIS

The work done to this point is the job of the laboratory technician. However, it is the responsibility of the engineer to insure that the CBR data is properly obtained and presented. More importantly, analysis of the data with an understanding of how the result affects the design and impacts on economic considerations is the key responsibility of the engineer.

For the purposes of this subcourse, it is essential that the engineer realize that soil placement at OMC and the most compactive effort possible are not always the answers to good construction.

Establish a density range at which soil will be placed in the field. Minimum limits for field compaction requirements are based on settlement criteria and are given in Table 6. To facilitate construction, specify a reasonable range of densities which can be economically obtained and then examine the strength values which would occur within that range. Establishment of the density range depends to a large degree on economics. The greater the latitude given the builder, the better are the changes of the soil being placed within established limits. However, if an extreme range is stipulated, the CBR value on the Family of Curves Graph (Figure 37) allowed for design might be reduced and thicker pavement structure could be required. Experience has shown that a 5 percent range (i.e., 90 to 95 percent of maximum CE 55 dry density) is reasonable.

For this example, the soil according to Table 6 must be placed at least 90 percent of maximum CE 55 dry density. It will be assumed that experience with the soil shows that 93 to 98 percent of maximum CE 55 dry density can be achieved with reasonable effort. This means that the limits of densities will be:

$$0.93 \times 130 = 120.9 \text{ pcf}$$

$$0.98 \times 130 = 127.4 \text{ pcf}$$

The limits can be imposed on the CBR family of curves by drawing two vertical lines at 120.9 and 127.4 pcf.

Determine the assured CBR values between the specific density limits, using the Family of Curves. If the builder is going to be allowed to place the soil between 120.9 and 127.4 pcf, this step involves determining the CBR values obtained for each moisture content. By observing the change in CBR for any specific moisture content line between the two density limits, it can be seen that a range of strengths is possible. Since the builder will be allowed to place the soil anywhere between the established density limits, the CBR value selected as a potential density strength should represent the worst case. Using 10 percent moisture as an example, the CBR at 120.9 pcf is 8.5. At 127.4 pcf the CBR is a maximum of 11.3. Of the two, 8.5 is the

minimum strength that can be counted on for the specified density range. We followed this procedure for the remaining moisture contents, using the Family of Curves, and tabulated the results as follows:

w(moisture)	CBR
10	8.5
11	9.2
12	10.2
13	11.3
14	13.6
15	10.3
16	7.4
17	5.4
18	4.2

Determine the CBR value for potential moisture content specification ranges. As with the density range specified in Step 9, it is desirable to have a moisture content range which can be economically achieved in the field. Within the overall range of investigation (OMC +4 percent, a smaller specification range which gives the greatest assured CBR will be determined. Experience has shown at a 4 percent range (i.e., some value +2 percent) is a reasonable requirement, but not an absolute rule. The engineer may specify a smaller range to achieve a larger design CBR and a reduction in pavement thickness requirements, but this savings in pavement materials may be offset by increased costs associated with difficulties in meeting the more stringent requirements. Conversely, for some soils an expanded moisture content specification may have little effect on the design CBR. For the example problem a 4 percent specification range will be considered. One possible range is 10 to 14 percent. If the engineer specified that the soil be placed within these limits, the worst possible strength that would be realized is a CBR of 8.5. Such an analysis can be done for the other possible 4 percent ranges, and the result is as follows:

w(range)	CBR
10 - 14	8.5
11 - 15	9.2
12- 16	7.4
13 - 17	5.4
14 - 18	4.2

Select the moisture content range which gives the greatest design CBR. In steps 10 and 11, CBR values were selected based upon the premise that the engineer is going to allow the builder to place the soil anywhere between potential moisture content and density specification limits. Now it is time for the engineer to select the set of limits he desires. From the tabulation in Step 11, it can be seen that the soil, if placed between 11 and 15 percent moisture, will give the largest of the possible CBR values. Thus 9.2 becomes the design CBR, and the field quality control measures to be used to insure that a CBR = 9.2 is achieved are:

Compaction from 93 to 98 percent of maximum
CE 55 dry density of 120.9 to 127.4 pcf.

SUMMARY

This technique for determining a design CBR provides for a strength measure of at least 9.2 when the associated density and moisture content ranges are adhered to. Greater strengths will be realized within the specified limits, but the value obtained allows the engineer to size the structure for the worst condition. It should be noted that for this soil and the size of the limits used, the greatest assured strength did not occur for the 4 percent moisture content range centered on OMC. This is a phenomenon which has been found to occur for many soils having appreciable clay contents. Also of importance is the fact that the analysis was based upon an initial selection of density limits that meet the minimums given in Table 6 to see if an adjustment to these limits will yield greater strengths.

TEST PROGRAM FOR SWELLING OR EXPANSIVE SOILS

There is a small group of soils which can display the characteristics of objectionable volumetric expansion after being compacted and subjected to subsequent saturation. This presents a problem in pavement design as this expansion or swell can damage the structure by means of a “reverse-settlement” mechanism. The measure of swell used by the Corps of Engineers is termed the “free swell index” which is expressed as a percentage of the initial sample height. Objectionable swell is defined as that in excess of 3 percent. Experience has shown that the plasticity index (PI) is an excellent indicator of expansive soils. The following guidelines have been suggested:

	Swell Potential
PI 0-14	Not Expansive
PI 14-25	Marginal
PI 25-40	Critical
PI 40	Highly Critical

Although a high PI does not guarantee that the soil is expansive, critical soils should be checked more closely for swell tendencies.

The potentially expansive soils by USCS classification are CHs, MHs, and OHs. The test procedure for determining a design CBR for a expansive soil is similar to that previously discussed for the non-swelling soil, but the objective is not exactly the same. For non-swelling soils, the object is to find the greatest assured CBR value for some range of densities and moisture contents, whereas the objective of the test program for the expansive soils is to find the moisture content ranges which will preclude objectionable swell and provide the highest soaked CBR. Generally, the minimum swell and the highest soaked CBR will occur at a molding moisture content of OMC. Follow along the example of such a test program for a CH soil taken from the subgrade at the proposed “Airfield Delta.” As the majority of the steps are similar to those developed for the case of non-swelling soils, only differences will be discussed.

Establish the OMC of the soil at 55 blows/layer.

Establish a moisture range for CBR investigation. The OMC +4 percent range of investigation may not apply. It may be necessary to prepare samples over a wide range of moistures with the majority of the work being done on samples wet at OMC. In the example, samples were prepared over a range of OMC ±8 percent.

Compact samples within the moisture content range of investigation at different levels of compactive effort. As swelling soils usually being tested will be cohesive and have a CBR less than 20, compaction must be at no less than 90 percent of maximum CE 55 dry density. An upper limit can be established by reason of practicality as expansive soils are very difficult to compact at levels greater than 100 percent of maximum CE 55 dry density. Therefore, laboratory compactive efforts of 12, 26, and 55 blows per layer are adequate for nearly all cases.

Soak samples and measure swell. This step is monitored more closely than in the non-swelling case. For each sample, the expansion is measured, the percent swell is computed, and the percent swell is plotted against the molding water content. As an example, the triangular data point at 10 percent moisture on the attached "swell data curve" (Figure 38) was obtained as follows:

Initial sample height = 5.00 inches
Height after soaking = 5.25 inches
Molding water content = 10 percent
Level of compactive effort = 55 blows/layer

$$\text{Free Swell Index or Percent of Swell} = \frac{5.25 - 5.00}{500} \times 100 = 5.0 \text{ percent}$$

After obtaining all data points, a curve is fit from which it can be ascertained that only soil placement at molding moisture contents of 14 percent or greater is acceptable.

NOTE: That to limit swell below 3%, values of moisture contents must be above 15%.

Perform CBR penetration tests and determine corrected CBR for each sample.

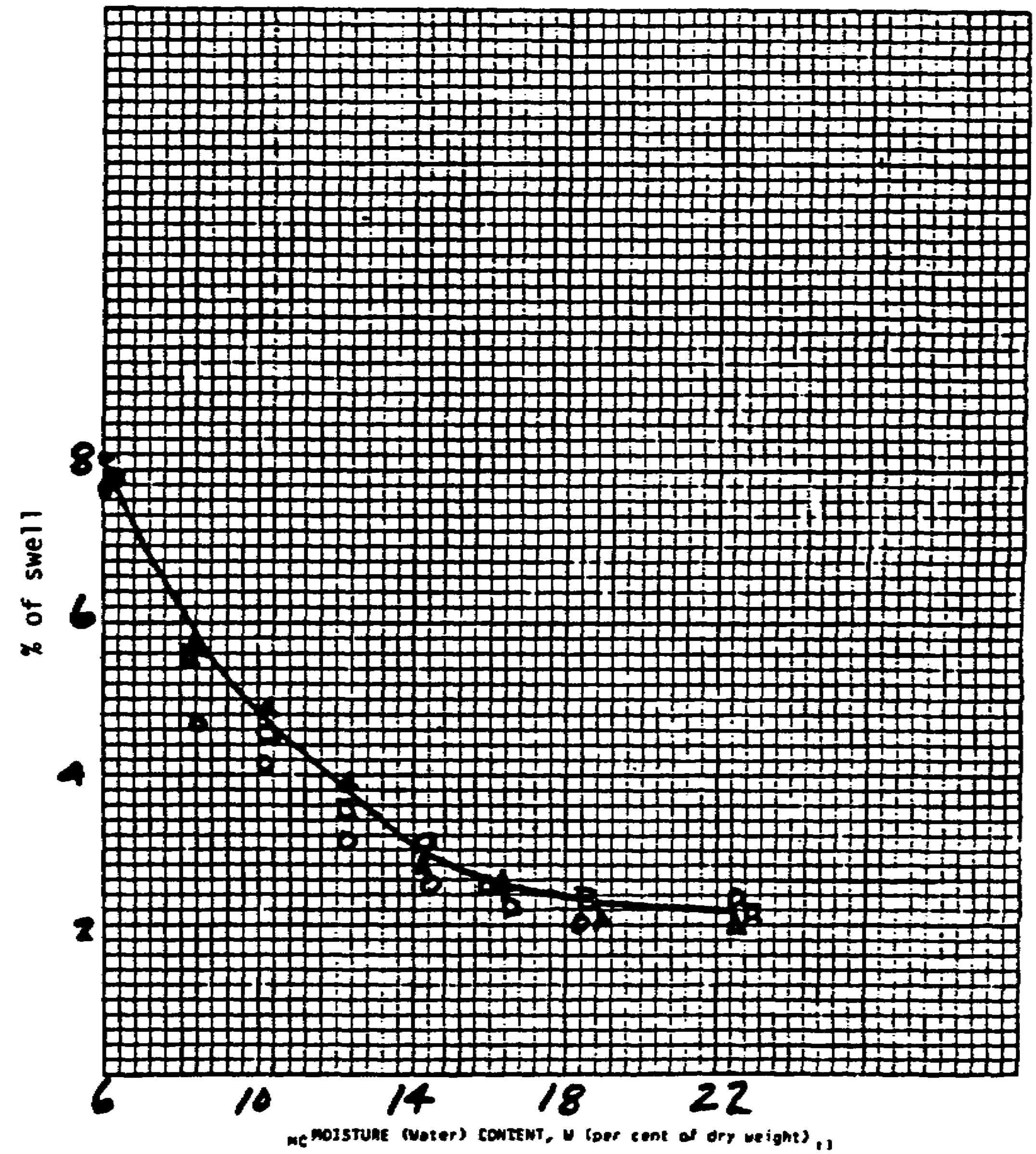
Plot the data on graphs of dry density versus molding moisture content and corrected CBR versus molding moisture content.

Reformat data on CBR family of curves data sheet.

Plot the CBR family of curves.

Establish a density range at which soil will be placed in the field. For this example, it will be assumed that prior experience or benefit of a test strip is not available. Hence, only the guidelines from Table 1 will be used. The minimum level of compaction is 90 percent of maximum CE 55 dry density and, assuming a reasonable specification range, the upper limit will

FIGURE 38. SWELL DATA CURVE



be set at 95 percent of maximum CE 55 dry density. The actual densities are:

110 x .90 = 99 pcf
110 x .95 = 104.5 pcf

As in the previous example, the above limits are shown by two vertical lines on the CBR family of curves (see Figure 39).

Determine the assured CBR values between the specified density limits. As more than 3 percent swell is not acceptable, evaluation of the CBR values at moisture contents less than 14 percent is needless. The CBR values for the applicable moisture contents are as follows:

w	CBR
14	3.4
15	4.2
16	3.2
17	2.2
18	1.3
19	.9
20	.4

Determine the CBR values for potential moisture content specification ranges.

w(range)	CBR
14 - 18	1.3
15 - 19	.9
16 -20	.4

Select the moisture content range which gives the greatest design CBR. From the step above, it can be seen that the 14 to 18 percent range gives largest CBR. Thus the design CBR is 1.3, an this value is obtained when the soil is placed at:

w = 14 - 18 percent
d = 99.0 - 104.5 pcf

As an engineer the first option you must consider when you encounter an expansive soil is going some place else to build the structure. When moving the site is not feasible, this technique allows for determination of a design CBR at which swell is not excessive. It is emphasized that obtaining this design value was done at the expense of strength. This technique does not provide for the advent of the soil being dried to a moisture content less than the amount at placement. Should such extreme drying take place, expect shrinkage and pavement failure. However, as an engineer, you have to your advantage the fact that such soils will normally be protected from drying by the overlying pavement. Another alternative to building on expansive soils is chemical stabilization. For example, addition of small amounts of lime considerably reduces the potential for shrinkage and swell.

FIGURE 39. CBR DATA

PROJECT AirField Delta
SOIL CLASSIFICATION CH
LOCATION OF SOIL STA 8+50
DATE OF TESTS 9 Aug 95
GROUP # NA
NAME SFS Hardcore PFC Auger head

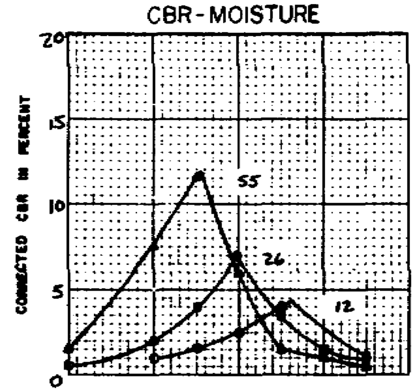
DATA SUMMARY

MOLD NO.	BLOWS PER LAYER	MOISTURE CONTENT w %	DRY DENSITY PCF	CORRECTED CBR %
1	12	10.0	95.0	1.0
2		12.0	96.5	1.5
3		14.0	97.5	2.5
4		16.0	98.5	4.0
5		20.0	98.0	1.2
6	26	6.0	94.0	0.5
7		10.0	98.5	2.0
8		12.0	102.0	4.0
9		14.0	103.5	7.0
10		16.0	104.0	3.5
11		18.0	103.0	1.5
12		20.0	101.0	1.0
13	55	6.0	100.0	1.5
14		10.0	107.0	7.5
15		12.0	109.0	11.5
16		14.0	110.0	6.0
17		16.0	109.5	1.5
18		18.0	102.5	1.0
19		20.0	104.0	0.5

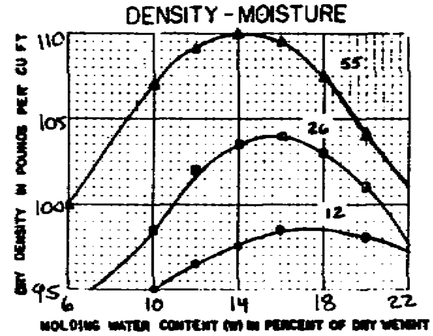
CBR FAMILY OF CURVES DATA

w (%)		12 BLOWS/LAYER	26 BLOWS/LAYER	55 BLOWS/LAYER
12	γ_d	96.5 LBS/FT³	101.7 LBS/FT³	109.3 LBS/FT³
	CORR. C_{BR}	1.5 %	4.0 %	11.5 %
13	γ_d	97.1 LBS/FT³	102.8 LBS/FT³	109.7 LBS/FT³
	CORR. C_{BR}	2.0 %	5.4 %	9.2 %
14	γ_d	97.6 LBS/FT³	103.5 LBS/FT³	110.0 LBS/FT³
	CORR. C_{BR}	2.5 %	7.0 %	6.0 %
15	γ_d	98.1 LBS/FT³	103.9 LBS/FT³	109.8 LBS/FT³
	CORR. C_{BR}	3.3 %	4.9 %	3.4 %
16	γ_d	98.4 LBS/FT³	104.0 LBS/FT³	109.5 LBS/FT³
	CORR. C_{BR}	4.0 %	3.5 %	1.5 %
17	γ_d	98.6 LBS/FT³	103.7 LBS/FT³	108.8 LBS/FT³
	CORR. C_{BR}	3.8 %	2.4 %	1.3 %
18	γ_d	98.5 LBS/FT³	103.0 LBS/FT³	107.5 LBS/FT³
	CORR. C_{BR}	2.7 %	1.5 %	1.0 %
19	γ_d	98.4 LBS/FT³	102.0 LBS/FT³	105.8 LBS/FT³
	CORR. C_{BR}	1.8 %	1.1 %	0.8 %
20	γ_d	98.0 LBS/FT³	101.0 LBS/FT³	104.0 LBS/FT³
	CORR. C_{BR}	1.2 %	1.0 %	0.5 %

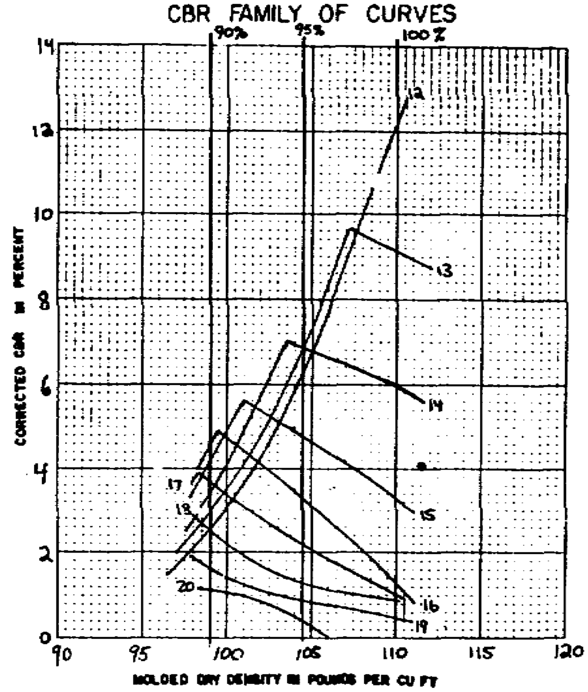
CBR-MOISTURE



DENSITY-MOISTURE



CBR FAMILY OF CURVES



TEST PROGRAM FOR FREE-DRAINING SOILS

Determination of a design CBR for this group of soils requires the least testing of the three molded laboratory test programs. Table 5 gives the USCS classification and the uses of the soils that fall into this group. The ease in testing is due to the free-draining characteristics or lack of fines in the soil. For such soils, field placement is relatively easy. To insure maximum dry density for any level of compactive effort, the only necessary control measure is to have more water available than that required for the maximum dry density at the appropriate level of compactive effort. From the corrected CBR versus molding water content curves, the same pattern can be seen in relation to moisture content as to dry density. Soils placed wetter than the limiting moisture content achieve the maximum CBR possible for that level of compactive effort. In other words, moisture contents of loose soils above the limiting values have little bearing on the strength of a soil after compaction. This makes laboratory testing, field placement, and field control a relatively easy matter. To illustrate what must be done to arrive at a design CBR, the steps as outlined in the previous examples will again be followed.

Establish the OMC of the soil at 55 blows/layer. The OMC for this example is the limiting moisture content or 8 percent. To insure that a free-draining soil is being tested, this curve should display a maximum dry density at a limiting moisture content, and will display a concave upward shape.

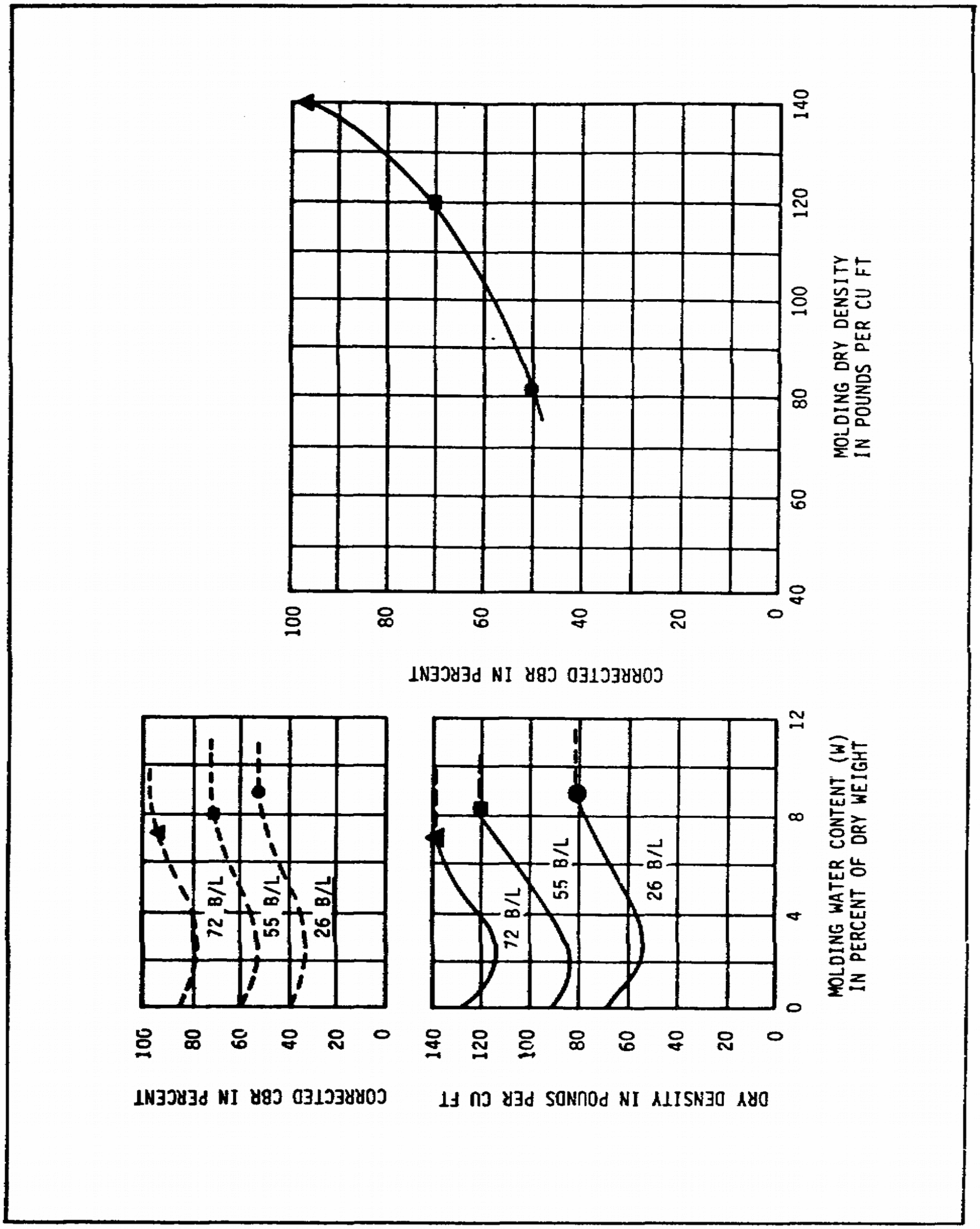
Compact samples at different levels of compactive effort. Compaction curves must be made for three levels of compactive effort up to the limiting moisture contents. As these soils frequently have CBR values greater than 20, the placement compactive effort is in excess of 100 percent of maximum CE 55 dry density. Therefore, 25, 55, and 72 blows/layer are usually used.

Soak samples and measure swell. Swell measurements are not required. Eliminate soaking when it is determined that saturation does not affect strength.

Perform CBR penetration tests. Only the samples at the limiting moisture contents for each level of compactive effort need be tested. Normally more than one sample at the limiting conditions will be made for each level of compactive effort and all should be tested.

Plot the data on graphs of dry density versus molding moisture content and corrected CBR versus molding moisture content. Only the plot of dry density versus molding water is required. The corrected CBR versus molding water content graph (Figure 40) is presented only for discussion.

FIGURE 40. CBR ANALYSIS SHEET



Plot CBR family of curves. This graph can be condensed into a single line. The three data points are obtained by plotting the corrected CBR against the associated dry density at the limiting moisture content.

Establish a density range at which the soil will be placed in the field. Using the criteria from Table 5 and noting that the CBR for this soil is always greater than 20, the minimum level of compaction allowed is 100 percent of maximum CE 55 dry density. As there is a lack of additional information, specify 100 to 105 percent of maximum CE 55 dry density. This means compaction between:

1.00 x 120 = 120 pcf
1.05 x 120 = 126 pcf

Determine the design CBR and placement moisture content. From the family of curves, it can be seen that the minimum CBR is 70 at 120 pcf. The placement moisture content necessary to insure that this strength is obtained is 8 percent or greater.

SUMMARY

It can be seen that considerably greater CBR values can be achieved if more field compaction is applied to the soil. If this is not too costly, it may be advantageous to specify greater densities. Lastly, it must be emphasized that the short cuts used in this procedure are dependent upon the fact that the soil is actually free draining. This can be determined from the shapes of the compaction curves.

FIELD CBR TESTS (IN-PLACE TESTS)

As a part of flexible pavement design, it will be necessary to determine the strength of the subgrade soil at its natural density. To accomplish this, the CBR penetration apparatus can be mounted on a vehicle.

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PRACTICE EXERCISE FOR LESSON 5

Instructions

Check your understanding of Lesson 5 by completing the practice exercise. There is only one correct answer to each question. Try to answer all of the questions without referring to the lesson material.

When you have completed all of the questions, turn the page and check your answers against the correct responses. Each correct response is referenced to specific portions of the lesson material so that you can review any questions you have missed or do not understand.

Before going on to the Examination, review all of the lessons and practice exercises to review the materials you do not understand or any questions you have missed.

1. The object of the CBR Test Program is to define
   a. soil placement conditions which give the greatest measure of strength in a laboratory setting.
   b. the principles of pavement design.
   c. mandatory soil classifications contained in the job specifications.
   d. parameters of a deliberate soil survey.

2. The further a soil is beneath a load
   a. the more soil strength is required to support that load.
   b. the less soil strength is required to support that load.
   c. minimum trafficability is required.
   d. maximum trafficability is required.

3. "Highest quality structural materials having strengths of nearly 100% CBR" best defines
   a. select materials.
   b. subbase materials.
   c. asphalt materials.
   d. base course materials.

4. The nature of the soil in military construction projects will determine
   a. the CBR tests employed.
   b. the nature of the profile report to be submitted.
   c. the amount and type of laboratory work required.
   d. the method of testing to be employed.

5. Soils with which of the following materials will cause unsatisfactory CBR Test variations?
   a. Clay or sand.
   b. Silts or gravel.
   c. Clay or silts.
   d. Gravel or stone.

6. Which is NOT an advantage of the CBR Test?
   a. The test must be run to exact standards in order for the design tables to be valid.
   b. Testing can be done on samples representative of future water conditions.
   c. The CBR methods adapt more quickly to airfield pavement design for immediate use than any other method.
   d. The test can be performed by personnel with relatively little experience and training.

7. Identify the FIRST step in the test program for non-swelling soils.
   a. Establish a moisture range for CBR investigation.
   b. Perform CBR penetration tests and determine corrected CBR for each sample.
   c. Compact samples within the moisture content range of investigation.
   d. Establish the OMC of the soil at 55 blows/layer.

8. The definition of objectionable swell is
   a. soil swell in excess of 7 percent.
   b. soil swell in excess of 5 percent.
   c. soil swell in excess of 3 percent.
   d. soil swell in excess of 1 percent.

9. A design CBR for which of the following requires the LEAST testing?
   a. Free-draining soils.
   b. Swelling soils.
   c. Non-swelling soils.
   d. Draining soils.

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ANSWER SHEET FOR PRACTICE EXERCISE

Lesson 5		Learning Event
1.	a	1
2.	b	1
3.	d	1
4.	c	1
5.	d	2
6.	a	2
7.	d	3
8.	c	3
9.	a	3